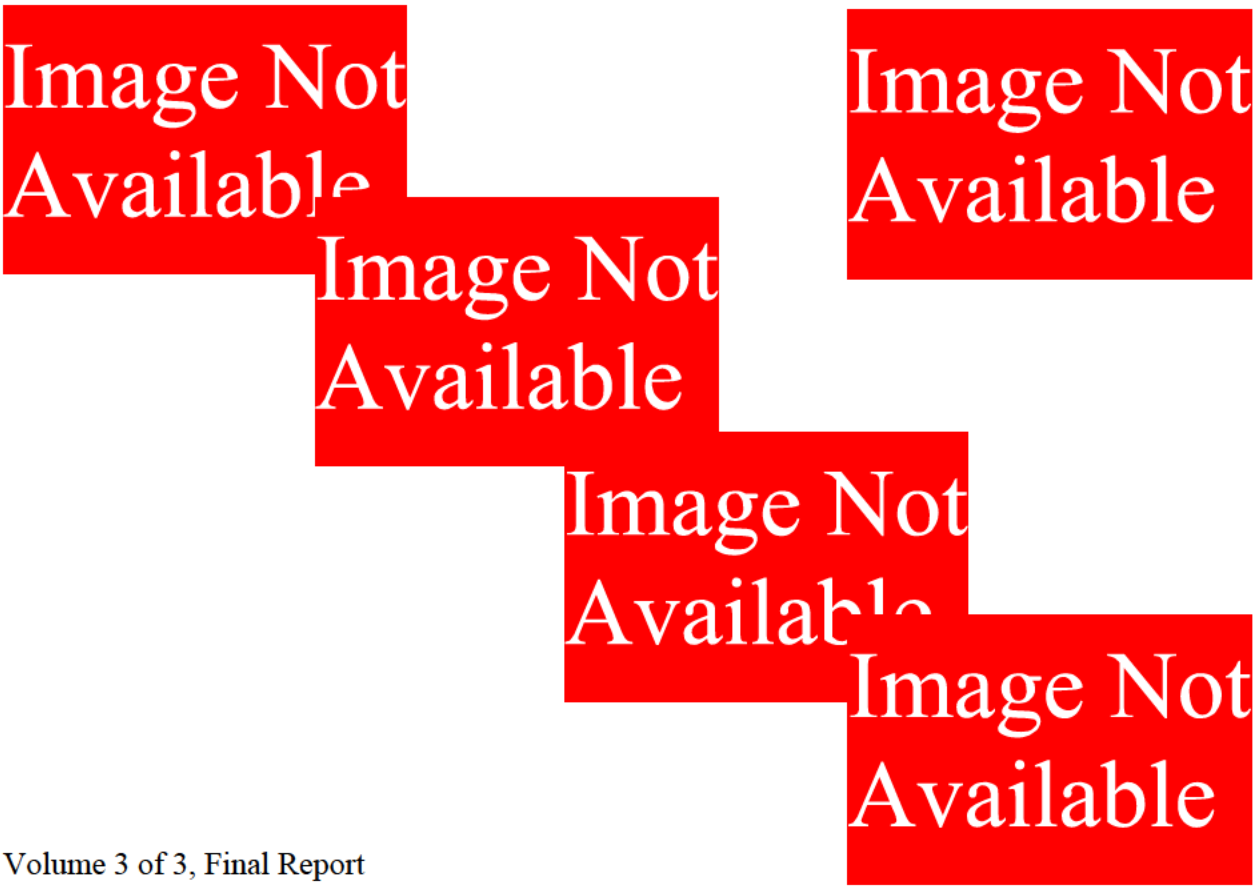
Metra Electric District

MOTIVE POWER STUDY

Evaluation of Traction Power System

Project Definition and Concept Planning



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Volume 3: Project Definition and Concept Planning

List of Contents

1. INTRODUCTION 1.1
- 1.1 HISTORICAL PERSPECTIVE 1.1
- 1.2 PURPOSE OF THE STUDY 1.4
- 1.3 SCOPE OF WORK 1.5
- 1.4 METHODOLOGY 1.6
- 1.5 WORK PRESENTATION 1.7

2. DESIGN CRITERIA 2.1
- 2.1 INDUSTRY STANDARDS, CODES, AND REGULATIONS 2.1
- 2.2 DESIGN ENVIRONMENT AND CRITERIA 2.1
- 2.3 FUTURE SYSTEM OPERATING REQUIREMENTS 2.2

3. ROLLING STOCK 3.1
- 3.1 BASIC ROLLING STOCK CONFIGURATION OPTIONS 3.1
- 3.2 VEHICLE OPTIONS CONSIDERING SYSTEM TYPE 3.1
- 3.3 ELECTRIC MULTIPLE UNITS 3.2
- 3.4 LOCOMOTIVE POWER WITH PUSH-PULL BI-LEVEL CARS 3.3
- 3.5 TRAIN PERFORMANCE SIMULATIONS 3.4
- 3.6 ROLLING STOCK QUANTITY ESTIMATE 3.5
- 3.7 COST ESTIMATES 3.6

4. TRACTION POWER SYSTEM 4.1
- 4.1 SUPPLY SYSTEM CONFIGURATIONS 4.1
- 4.2 UTILITY COORDINATION 4.6
- 4.3 ELECTRIFICATION SYSTEM AND VOLTAGE 4.10
- 4.4 LOCATIONS OF TRACTION POWER SUPPLY FACILITIES 4.10
- 4.5 SUBSTATION RATINGS 4.13
- 4.6 REGENERATION 4.14
- 4.7 NORMAL AND EMERGENCY SYSTEM OPERATION 4.15
- 4.8 CRITICAL ELECTRIFICATION SYSTEM COMPONENTS 4.16
- 4.9 SYSTEM CONVERSION AND COORDINATION WITH NICTD 4.16

5. CATENARY SYSTEM UPGRADE 5.1
- 5.1 CATENARY SYSTEM CONFIGURATIONS 5.1
- 5.2 SHORT TERM UPGRADE 5.1
- 5.3 LONG TERM UPGRADE 5.2
- 5.4 CATENARY SYSTEM CONDUCTOR SIZES 5.2

5.5 AUTO-TENSIONED CATENARY SYSTEM 5.3
5.6 CATENARY SYSTEM CLEARANCES 5.4
5.7 UPGRADE IMPLEMENTATION PLANNING 5.6

6. SIGNAL SYSTEM 6.1
6.1 SIGNAL SYSTEM CAPABILITY FOR 79 MPH OPERATION 6.1
6.2 SIGNAL SYSTEM COMPATIBILITY 6.2
6.3 CURRENT METRA/NICTD PROJECTS AND STUDIES 6.3

7. COMMUNICATIONS SYSTEM 7.1
7.1 GENERAL 7.1
7.2 COMMUNICATION PROVISIONS FOR NEW FACILITIES 7.1

8. STORAGE AND MAINTENANCE FACILITIES 8.1
8.1 OBJECTIVE 8.1
8.2 POTENTIAL FOR STORAGE GROWTH 8.1
8.3 STORAGE REQUIREMENTS FOR FLEET ALTERNATIVES 8.3

9. LIGHT AND POWER TRANSMISSION LINE 9.1
9.1 FUTURE LOADS 9.1
9.2 LINE AUGMENTATION 9.1
9.3 OTHER CONSIDERATIONS 9.1

10. REAL ESTATE REQUIREMENTS 10.1
10.1 LAND REQUIREMENTS 10.1
10.2 SITE VISITS 10.1
10.3 FUTURE ACTIVITIES 10.2

11. ENVIRONMENTAL IMPACT 11.1
11.1 WAYSIDE FACILITIES 11.1
11.2 ELECTROMAGNETIC FIELDS 11.2

12. SYSTEM COST ESTIMATES 12.1
12.1 GENERAL 12.1
12.2 CAPITAL COST ESTIMATE 12.1
12.3 OPERATIONS AND MAINTENANCE COST ESTIMATE 12.5
12.4 LIFE CYCLE COST ESTIMATE 12.5

13. CONCLUSIONS AND RECOMMENDATIONS 13.1
13.1 ROLLING STOCK 13.1
13.2 TRACTION POWER SUPPLY SYSTEM 13.1
13.3 CATENARY SYSTEM 13.2
13.4 SIGNAL SYSTEM 13.2
13.5 COMMUNICATIONS SYSTEM 13.3
13.6 STORAGE AND MAINTENANCE FACILITIES 13.3
13.7 LIGHT AND POWER TRANSMISSION LINE 13.3

13.8 REAL ESTATE REQUIREMENTS 13.3
13.9 COST ESTIMATES 13.4

Appendix A - GLOSSARY OF TERMS A.1
A.1 GLOSSARY OF TERMS A.1
A.2 LIST OF ABBREVIATIONS A.4

Appendix B - TPS INPUT DATA B.1
B.1 ALIGNMENT DATA B.2
B.2 TRAIN DATA B.2

Appendix C - TPS OUTPUT DATA C.1
C.1 EXPRESS TRAINS, HARVEY ZONE C.2
C.2 EXPRESS TRAINS, FLOSSMOORE ZONE C.3
C.3 EXPRESS TRAINS, UNIVERSITY PARK ZONE C.4

Appendix D - ROLLING STOCK COST ESTIMATE D.1
D.1 ROLLING STOCK CAPITAL COST D.1
D.2 OPERATIONS AND MAINTENANCE COST D.1
D.3 COST SUMMARY D.1

Appendix E - ENS INPUT DATA E.1
E.1 ELECTRICAL NETWORK DATA E.2

Appendix F - ENS OUTPUT DATA F.1
F.1 EXISTING 1,500 V DC SYSTEM AUGMENTATION F.2
F.2 NEW 12.5 kV AC SYSTEM F.4
F.3 NEW 25 kV AC SYSTEM F.5
F.4 SUBSTATION RATING PROCEDURE F.6

Appendix G - SYSTEM COST ESTIMATES G.1
G.1 SYSTEM CAPITAL COST G.1
G.2 SYSTEM OPERATIONS AND MAINTENANCE COST G.2
G.3 COST SUMMARY G.2

Appendix H - EXISTING 1,500 V DC SYSTEM COST AUGMENTATION BACKUP H.1

Appendix I - NEW 12.5 kV AC SYSTEM COST BACKUP I.1

Appendix J - NEW 25 kV AC SYSTEM COST BACKUP J.1

1. INTRODUCTION

1.1 HISTORICAL PERSPECTIVE

1.1.1 Railroad Beginning

The rail lines now operated by the Metra Electric District were originally built by the Illinois Central Railroad (IC). The IC had begun operating southward from Hyde Park (53rd Street) on May 22, 1852. The first IC suburban service trains began running on July 21, 1856 from Randolph Street terminal to Hyde Park. The ridership grew at a spectacular rate, doubling between 1900 and 1920, by which time there were 294 daily train runs. To cope with the high number of passengers, the IC developed a highly efficient operation, introduced high level station platforms, purchased the Sullivan type cars with 10 doors per side, and began considering electrification.

1.1.2 Choice of Electrification System

Various systems of electrification were carefully studied before a choice was made. The choice was between direct current (DC) systems at moderate electrification voltage and alternating current (AC) systems at high electrification voltage. The DC systems would require more elaborate equipment on the wayside, but very simple equipment on the trains. The AC systems, on the other hand, required heavier and more expensive equipment on the trains, but minimal equipment along the wayside.

AC electrification system thus would be a good choice for a long distance electrification involving hundreds of miles of line and relatively few locomotive-hauled or multiple unit (MU) trains. DC system, on the other hand, seemed to be the best choice for the IC system electrification, which would involve only a relatively short line, but hundreds of electric MU cars. Since the traffic on IC's Mainline beyond the suburban territory was too light to offer any economic justification for long distance type of electrification, the choice thus was made to use a 1,500 V DC system. This voltage, about double that used by the elevated system and the streetcars, greatly reduced line losses and allowed substations to be spaced along the route at wider intervals.

1.1.3 Beginning of Electric Service

On July 21, 1926, the first electric suburban train ran from Randolph Street to 67th Street. Formal inauguration of electric operation through to Matteson took place on August 27, 1926. Soon electric trains covered all suburban service on the Mainline to Matteson, and the South Chicago and Blue

Island Branches. By 1929, 542 daily electric suburban trains were handling 121,000 daily passengers and the IC electrification was a resounding success.

1.1.4 Equipment Innovations

While the electrification was initially applied only to the suburban service, it was intended that it would eventually take over all freight and long-distance passenger operation within the city to eliminate smoke and noise of steam operation. The electrification system equipment was selected and designed with great care. For example, the IC requested the two major manufacturers of electrical equipment, General Electric and Westinghouse, to offer traction motors which were completely interchangeable. After extensive testing both motors were found to be satisfactory, and half of the order was placed with each supplier. The control equipment for all cars was supplied by General Electric.

Most of the substations had motor-generator sets to convert the AC power from the utility to the DC power required by the trains. A few of the substations were equipped with mercury arc rectifiers which were just beginning to be available. With no moving parts, the rectifiers required much less supervision and maintenance. A major innovation was that the substations would be owned and operated by Commonwealth Edison, rather than by the railroad. The utility was more accustomed to substation operation than the railroad and realized savings in equipment maintenance through economies of scale.

1.1.5 Recent Equipment Enhancements

In the 1970's the value of commuter service to the community was recognized and the South Suburban Mass Transit District, a predecessor of Metra, was created and provided assistance to the IC, by then merged into the Illinois Central Gulf (ICG) railroad.

New cars were purchased to replace the original electric cars. Following the lead of most of the other railroads operating suburban service in Chicago, the new cars were of the bi-level gallery type, providing the maximum number of seats per car. Because the IC operation, especially at the congested loop stations and the terminal, required passengers to be able to board and alight very quickly, the cars were designed with more doors than those of other railroads.

At the same time, automated fare collection was introduced on the ICG Suburban service as a major innovation. This was the first large-scale application of a system using magnetically-encoded tickets and fare gates which read the tickets electronically. Also, the original rotary converters and mercury-arc rectifiers in the traction power substations were replaced with solid-state rectifiers.

1.1.6 Metra Electric District System Today

In 1982 the operation of the Electric District has been taken over by Metra. Since the suburban passenger operation has been separated from the long-distance passenger and freight operations, the transition has been easier than in cases where commuter and freight operations had to be integrated on jointly-owned tracks.

Immediately upon beginning operation, Metra embarked on a modernization program of its facilities. This modernization included rehabilitation of the existing equipment as well as installation of new facilities.

The Metra Electric District rolling stock consists of 165 Highliner cars built between 1971 and 1978. All cars were overhauled between 1989-1996. The cars have been re-cambered, corroded steel has been replaced, and the car systems were reconditioned with some upgrades. However, the cars will soon reach the end of their useful life.

In the traction power substations, PCB-filled traction power transformers were replaced with dry-type or oil-filled transformers and the original AC and DC circuit breakers were replaced with modern switchgear. The DC feeder cables, the 4.16 kV lighting and power cables, and the 2.3 kV signal power supply cables were also replaced. Additional systems were introduced, such as the supervisory control and data acquisition system (SCADA), the DC circuit breaker fail protection, and the transfer trip protection.

The catenary system has undergone major rehabilitation. Contact wire wear is continuously monitored and significant sections of contact wire have been replaced. Although old, the present system is in a remarkably sound condition. The tensions in the conductors are being monitored and retensioning is performed as required. De-wirements are rare and a program of pole foundation repair is ongoing.

Much of the signal system today needs to be updated. The existing Mainline track circuits with US&S Model 15 relays are still very reliable but their maintenance and repair are costly, as the relays have not been available since the 1970's. The major interlockings, Randolph and Kensington, are in satisfactory condition being equipped with phase-selective coded track circuits. In the near future, the 67th Street Interlocking Tower is going to be replaced and split into three interlockings (65th, 67th and 69th) with the same type of track circuits. The Mainline south of Kensington is in the Centralized Traffic Control (CTC) territory and is controlled from the Central Control Facility (CCF).

The South Chicago Subdistrict signal system has had little or no updates since the 1950's. Along with maintenance of the many AC track circuits, maintenance of insulated joints is required. Because of the 36 (soon to be 38) at-grade crossings, much of the crossing protection has hold down circuits, station dwell time, speed measuring, and interlocking type relays for stick circuits.

The Blue Island Subdistrict is in marginally better condition than South Chicago Subdistrict. The single track systems includes one spring switch passing track.

The communication system for the Electric District is owned and operated by Metra. The system consists of telephone, radio, SCADA, station public address (PA), and station closed circuit televison (CCTV) subsystems. There are two control centers serving the system. The CCF is the principal communications control center for the entire railroad operated by Metra. The second facility is the Passenger Assistance Link (PAL) Center. PAL's main function is to provide a manned communications link, both audio and visual, to Metra passenger stations on the Electric District. The communication equipment located at passenger stations, power substations, and other rail right-of-

way (ROW) locations are connected to the two control centers by fiberoptic, coaxial, and copper cables. These communications connections are supplemented by telephone voice and data circuits leased from Ameritech.

The Metra Electric District has six maintenance and storage facilities, Randolph Street/North Terminal, Weldon/18th Street Yard, Kensington Yard (KYD), Blue Island Yard, Matteson/Richton Park Yard, and University Park Yard/South Terminal. The facilities serve for routine inspection, light repair, major repair and overhaul, exterior car wash, interior car cleaning, wheel truing, and car storage.

The Light and Power (L&P) Transmission System supplies AC electrical power to passenger stations, Maintenance-of-Way (MOW) buildings, street/subway lighting, interlocking towers, bridges, signal system equipment, snow-melter systems, and other locations along Metra Electric District routes. The system consists of two distinct transmission subsystems, L&P Power four-wire, three-phase distribution system rated at 4.16 kV/60 Hertz, and Signal Power two-wire, ungrounded, single-phase distribution system rated at 2.3 kV/60 Hertz. Each of the subsystems receives power from the traction power substations via wire atop the overhead catenary system supports. Duplicate power lines are installed on the most critical portions of the Mainline.

1.2 PURPOSE OF THE STUDY

Since inception of the original electrification system, the electrical equipment operated safely and reliably. Today, some of the original equipment is still in service after more than 70 years of continuous operation. Due to the equipment age, some of the subsystems and components may be at the end of their useful life and need to be upgraded or replaced.

Furthermore, the existing cars that replaced the original electric cars are 20-30 years old. The cars have already undergone one rebuilt cycle, and now the car bodies are deteriorating. The cars still use the obsolete and inefficient cam-controlled propulsion system. With significant investments for the system modernization already committed, and a new large investment to replace the 165 cars potentially ahead, Metra wishes to evaluate the next step in the electric system development and assess how to continue serving the commuter passengers in the new century.

Taking into account the recent and projected passenger volume increases, the primary purpose of this study is to determine the answers to the following fundamental questions:

- What are the rolling stock replacements options? Should the existing rolling stock be replaced with the same type of equipment or should new technology, such as AC propulsion, be introduced?
- Would it be advantageous to use locomotive-hauled trains with trailer cars?
- Should the existing 1,500 V DC traction power supply and distribution systems be retained and augmented with additional power supply facilities to supply the projected level of service, or should the system be converted to a new electrification system operating either at 12.5 kV AC or 25 kV AC electrification voltage?

If the existing system is retained, it is necessary to answer the following:

- What modifications to the existing traction power system are required to supply year 2020 traction loads?
- What new equipment is required and what are the equipment ratings?
- What is the realistic, least service disrupting, and most cost-effective approach for implementing the system augmentation?
- What additional system components need to be renovated and upgraded?
- What is the cost of the system augmentation and upgrade?

In the event that either the 12.5 kV AC or the 25 kV AC system is more advantageous to Metra, the following questions need to be answered:

- What should the configuration of the new system be?
- What impact would the voltage increase and use of commercial frequency have on vehicle modifications, overhead catenary system clearances, signaling system compatibility, and change of other miscellaneous subsystems?
- What would be the environmental impact of the system conversion?
- What would be the operational impacts of voltage and frequency changes on Metra and the Northern Indiana Commuter District (NICTD)?
- What is the realistic, least time-consuming, and most cost-effective approach for implementing the system conversion?
- How would the system conversion be accomplished with minimum disturbance to train operation during construction?
- How would the new system construction be coordinated with vehicle conversion?
- What other system improvements are necessary due to obsolete equipment and change in voltage and frequency?
- What are the impacts of construction of new transmission lines for power supply to new substations?
- What are the major risks to successful project implementation?
- What is the cost of the system conversion?

Additionally, an evaluation into the possibility of dual-power locomotive (DPL) use is required. In the event that Metra extends its service in the future, *e. g.*, to the proposed South Suburban Airport (SSA) planed to be located near Peotone, Ill, by the State of Illinois Department of Transportation (IDOT), the DPL-hauled trains would be an option to extension of the electrification system.

1.3 SCOPE OF WORK

The Metra Electric District consists of the Mainline rail route between the downtown Chicago Randolph Street Station and the University Park Terminal. There are also two spur rail lines branching off of this Mainline, the South Chicago Branch and the Blue Island Branch. The study evaluates the systems used on the Metra Electric District commuter lines as shown in Table 1-1.

Table 1-1 - Metra Electric District Commuter Lines

Line Name	Extent of the Study	Approximate Route Length (miles)	Number of Passenger Stations	Maximum Operating Speed (mph)
System Mainline	Randolph Street to University Park	31.4	34	65
South Chicago Branch	Mainline to South Chicago 93rd Street	4.7	8	30
Blue Island Branch	Mainline to Blue Island	4.4	7	30
Total System Under Study		**40.5**	**49**	

1.4 METHODOLOGY

The work on the project is divided into three tasks, and each task is, in turn, divided into subtasks as shown in Table 1-2.

Table 1-2 - Metra Electric District Study Tasks and Subtasks

Metra Study Tasks	Study Subtasks
Task 1: Data Collection, Site Inspection, Interviews, and Inventory of Existing System	1.1 Data Collection and Review 1.2 System Inspection and Evaluation 1.3 Staff Interviews 1.4 Inventory of Existing System
Task 2: Evaluation of Existing System	2.1 Existing Operation Criteria 2.2 Rolling Stock 2.3 Traction Power System 2.4 Catenary System 2.5 Signal System 2.6 Communications System 2.7 Storage and Maintenance Facilities 2.8 Light and Power Transmission Line 2.9 Real Estate Requirements 2.10 Environmental Impact 2.11 Cost Estimates 2.12 Recommendation and Implementation
Task 3: Project Definition/Concept Planning	3.1 Design Criteria 3.2 Rolling Stock 3.3 Traction Power System 3.4 Catenary System 3.5 Signal System 3.6 Communications System 3.7 Storage and Maintenance Facilities 3.8 Light and Power Transmission Line 3.9 Real Estate Requirements 3.10 Environmental Impact 3.11 Cost Estimates 3.12 Conclusions and Recommendations

The work performed in Task 1 is an indispensable effort which forms the cornerstone of the Motive Power Study. The purpose of the task is to prepare an overview and inventory of the Metra Electric District system elements, vehicles, and facilities.

Based on the Task 1, analysis of the existing Metra systems, vehicles, and facilities is performed in the Task 2 with regard to future system operation costs. A comprehensive power system study is performed for the current passenger density, and systems and facilities needing augmentation are identified. As some of the system components are more than 70 years old and might be close to the end of their useful life, consideration is given to future maintenance costs. The objective of this task is to evaluate and determine which parts of the Metra Electric District system can continue to be used, which parts need upgrading, and which parts need replacement.

In Task 3, alternative systems that could either supplement or replace the existing 1,500 V DC electrification system are evaluated taking into consideration passenger density projected for the year 2020. Any proposed electrification system needs to have sufficient capacity to supply adequate power to the trains and meet future system operating requirements. The objective of this task is to develop conceptual designs for at least three alternative systems, each capable of supporting Metra's operation projected to the year 2020. Impacts, benefits and costs of each system are required to be developed, and the most advantageous system for the Metra Electric District needs to be identified.

1.5 WORK PRESENTATION

Consistently with the three tasks outlined above, the Metra Motive Study report is presented in the following volumes:

- Volume 1 - Data Collection, Site Inspection, Interviews, and Inventory of Existing System
- Volume 2 - Evaluation of Existing System
- Volume 3 - Project Definition and Concept Planning

In order for each volume to be a stand-alone document, this introductory Section 1.0 is presented in each volume. For a comprehensive project overview, however, the reader should have an access to all three volumes.

2. DESIGN CRITERIA

2.1 INDUSTRY STANDARDS, CODES, AND REGULATIONS

All proposed designs and system alternatives developed for Metra were prepared in compliance with Metra's own standards, and in accordance with prevailing industry standards. Also, any relevant local, state, and federal codes and regulations were taken into account as appropriate for this level of study.

2.2 DESIGN ENVIRONMENT AND CRITERIA

Design criteria were developed for the rolling stock, traction power system, overhead catenary system, and the systems and facilities that might be impacted be the electrification system augmentation, upgrade, or replacement. The following criteria were included:

- Vehicles
  - Operating characteristics
    - Electric multiple units
    - Electric locomotives
    - Dual-power locomotives (DPLs)
  - Station-to-station run times and overall trip time for each route
  - Fleet size estimate
  - Peak and off-peak headways
  - Consist sizes
- Traction Power System
  - Substation nominal, no-load, maximum, and minimum voltages
  - Long-time, medium-time and short-time overloads
- Catenary System
  - Electrical clearances
  - Minimum catenary voltage
- Signal System
  - Maximum design speed
  - Minimum design headway
  - Signal block layout
- Communications System
  - Modifications required for augmented or new system
- Storage and Maintenance Facilities
  - Modifications required to accommodate future fleet

- Requirement for refueling facilities if dual-power locomotives are used
- Light and Power Transmission Line
  - Line capacity to support future loads
- Real Estate Requirements
  - Substation, switching station, paralleling station, and tie station requirements
  - Storage and maintenance facility expansion

2.3 FUTURE SYSTEM OPERATING REQUIREMENTS

2.3.1 Planning Assumptions

For purposes of this analysis, several observations and assumptions have been made relative to current operating conditions, and those forecast for the study year, 2020. These include the following:

- Current Metra Electric District ridership is slightly less than 12 million per year. This appears to be a stable figure after a sustained period of decline. As recently as in the 1960s, the service was carrying as many as 50% more passengers (18 million in 1969), and the service routinely handled annual ridership levels in the mid-20 millions when the service was electrified in the 1920s and 1930s. Ridership is reported to have peaked at 47 million in 1947.
- Metra's Planning Department has provided a "first-cut" demand forecast for 2020 which envisions an overall 20% increase in ridership above current, year 2000 level. While this forecast was characterized as a probable upper limit to growth, it seems a reasonable target at this point, given:
  - Recent modest improvement in Electric District ridership patterns.
  - Recent redevelopment trends in the City of Chicago, reversing population decline, and population growth in parts of the city characterized by post-industrial decline, typical of areas served by the Electric District.
  - Recent reversal of long-term trends in ridership decline on the CTA system, which serves urban core areas similar to some areas served by the Electric District.
  - A 20% increase over a 20-year period represents less than a 1% compounded growth rate, considered a very modest figure.
- The 2020 growth forecast provided has not been detailed by time of day, direction, or location on the line, either by branch or by indicating how this level of growth would be observed in terms of peak one-hour ridership across the maximum load point. Peak spreading is a typical phenomenon in Chicago, as in other major urban areas, suggesting the potential to add and/or lengthen trains outside the classic "peak" one hour period.
- Since no recommendation was made on the time period within which some additional service would be added, for the purposes of the traction power system analysis, the following assumptions will be made:
  - Two additional Metra trains and two additional NICTD trains will be placed in service in the peak hour.

- System improvements to allow for increase in train speed operation will be implemented before the year 2020. This will include provision of adequate traction power to the overhead catenary system, increase of efficiency of operation through interlockings, and upgrade of the signaling system.

2.3.2 Options for Increased Service

In order to accommodate the additional passengers, additional capacity will be required. Options available for increasing service include an increase of acceleration and braking rates, raising scheduled operating speeds, introduction of longer train consists, and scheduling of additional trains. These options are not entirely exclusive of one another. For example, if it were possible to "squeeze" an extra trip out of one consist by reducing round-trip cycle time, operating that train through constrained track and signal bottlenecks would still require investment in fixed facilities. The options are briefly evaluated below.

2.3.2.1 Increased Train Acceleration and Braking Rate and/or Operating Speeds

Increased acceleration and braking rates, as well as higher operating speeds, could theoretically permit Metra to cycle equipment more rapidly, and this would improve the passenger carrying productivity of the fleet.

Faster service would also be more attractive to the public. Faster trains could be a factor in helping Metra to realize its objectives of increased ridership, as well as continuing to improve productivity. Since Metra is planning to replace the entire fleet of Highliners, the advantages of this approach, should other constraints be removed, would include:

- Reduced size of new rolling stock fleet that would be otherwise required
- Reduced additional rolling stock storage space required
- Higher productivity of train operation personnel

The disadvantages include:

- Capital investment required for traction power supply system, signal system, track, and station upgrades
- Higher cost of track maintenance associated with higher speed
- Higher acceleration and braking rates require higher adhesion. Any factors such as weather or leaves on the rail that reduce adhesion could impact the schedule.

For the new fleet of rolling stock Metra is considering a speed increase from the existing top speed of 65 mph to 79 mph. The next step in speed increase, to 89 mph, would require installation of cab signals, and such installation would represent a major capital expense. If there is a possibility that cab signals might be mandated in the near future, then the vehicles might be designed for 89 mph operation.

The required signal system, track, and interlocking upgrades to improve the system throughput capacity and actually shorten equipment cycle time would involve considerable capital expense. Some of these improvements are desirable in their own right and are currently being implemented under various Metra contracts.

2.3.2.2 Introduction of Longer Train Consists

Lengthening of train consists to 8-car trains would permit Metra to accommodate more passengers per train, and provide higher passenger throughput on the system without a proportional increase in the number of trains operated. The advantages of this approach are:

- Minimal additional train operation personnel would be required

The disadvantages include:

- Additional rolling stock equipment would be required
- Additional rolling stock storage may be required
- Significant capital investment would be required to lengthen key platforms to accommodate the 8-car trains.

In the past, when passenger volumes were considerably greater and trains were longer, the Electric District stations had longer platforms. These were high maintenance costs wooden platforms which were in need of replacement with permanent concrete and steel platforms meeting minimum modern standards.

The introduction of electrified gallery cars, the Highliners, represented a strategy of accommodating the high passenger volumes with shorter consists, thus permitting, among other objectives, the replacement of longer platforms with shorter ones. Consistent with this strategy, most Electric District stations were retrofitted with shorter platforms. At present, Metra's longest trains consist of 6 cars or, in a few cases, 7 cars.

If future passenger traffic density should increase to a level warranting several 8 car trains, at least the key platforms served by Mainline trains running to points south of Kensington may justify lengthening. However, the basic fact remains that having rebuilt the Electric District stations with shorter platforms to accommodate shorter consists, there are now significant constraints to lengthening train consists as a strategy to deal with patronage growth.

A main set of platform constraints is found at Randolph Street station. Of the five station tracks currently available for regular passenger use, only Track 6 can readily accommodate 8-car trains without difficulty. The Tracks 3, 4 and 5, can handle 8-car consists with modified procedures involving blocking of doors from opening due to excessive platform gaps. Track 2 cannot accommodate consists exceeding 7 cars, and Track 1 is not really usable by passengers under present circumstances.

The Electric District Mainline generates about two-thirds of the present ridership and will continue to generate the majority of customers. However, significant constraints to train length increase exist

on the Mainline at the key stations. Van Buren Station and all stations south of Riverdale can accommodate only 6-car trains and would have to be extended for 8-car trains. Therefore, a selective program of platform extensions to accommodate the 8-car consists along the Mainline would represent a balanced approach of investment to enable operation of longer trains at the most heavily used part of the system.

2.3.2.3 Additional Trains

Putting more trains in service is the most direct way to accommodate more passengers and provide higher passenger throughput. The advantages of this approach are:

- No platform modification work would be required if train length is kept at maximum of six cars.

The disadvantages of this approach are:

- Additional rolling stock equipment would be required.
- Additional rolling stock storage would be required.
- Additional train operations personnel and an increased operating budget would be required.
- Capacity constraints would have to be removed.

Although a network simulation has not been conducted as part of this study, it is readily apparent from a evaluation of timetables, Operations Profile track charts, inspection of the physical plant, observation of operations, and discussions with operations staff, that the Electric Division faces significant capacity-limiting operating conditions. These conditions notwithstanding, the Electric Division is the most intensively operated of the Metra lines, and in some areas must surely rank among the most densely trafficked suburban rail services in the country. It is a tribute to the operating staff that they are able to achieve this level of performance under these sometimes difficult conditions.

The following two areas stand out in the consideration of capacity limitations:

- Randolph Street Station and its southern approaches and interlocking.
- Downtown stations and track arrangement.
- Track arrangements at and near Kensington, particularly the double track territory to the south.
- Limitations of the signal system

Constrained platform lengths at Randolph Street were already discussed above, but the density of traffic at the station and through its approaches is also an important matter in its own right. As an example, in the one hour between 4:45 and 5:45 PM, 21 departures and 5 arrivals are scheduled at the five-track terminal, an average of more than five revenue train movements per terminal track per hour. In addition to these Metra electric trains, five South Shore (NICTD) trains are also scheduled, and while they have their own terminal area and do not directly affect the Metra terminal tracks per se, these trains do have to pass through the same terminal approach trackage and interlocking, and, to the south, share Metra facilities as far as Kensington. Given significant track curves, gradients,

and low speeds on approach to the terminal, the overall arrangement is considered near its optimum sustainable operating capacity. While a full analysis would be required to confirm this preliminary conclusion, it appears that without some investment in trackwork and signal system, it would be difficult for this physical plant to absorb a significant increase in peak hour train movements.

To the south of the interlocking all trains stop at Van Buren Street Station, the second most important station in the system. The station is served by only three tracks and the platform lengths are limited. With the Electric Division dense pattern of trains, all being sorted into and out of a two-track segment at 11th Place, a situation approximating that of a bottleneck exists. With all trains again stopping at Roosevelt Road, numerous conflicting train movements affect the potential capacity of the overall system.

Fourteen miles south of Downtown, at Kensington (115th Street), NICTD's South Shore line branches off to the east, and just to the south of that, the Electric Division Blue Island line branches off to the southwest. The track arrangement requires that all Metra and South Shore trains to and from the Electric Division negotiate a narrowing from four tracks at 111th Street (Pullman), to three tracks, and then to two tracks at Kensington. The Kensington Station serves as a transfer point for the branching lines, and therefore, most trains are required stop at the station. Signal system have been upgraded to CTC to provide some flexibility to operations, but the combination of the availability of only two tracks and the slow South Shore branch movement create a constraint on operations. Streamlining the operation would involve capital investment.

2.3.3 System Operation in 2020

For purposes of this motive power analysis, assumptions have to be made about how the Metra Electric Division might accommodate year 2020 passenger boardings. The picture that emerges from a consideration of the technical and planning issues involved suggest that by 2020, Metra will implement a menu of improvements to both rolling stock and fixed facilities, as discussed above. The following specific assumptions underlie this analysis:

- Higher acceleration rate, braking rate, and operating speed. The new rolling stock is assumed to be capable of an initial acceleration rate of 2 mphps and a maximum operating speed of 79 mph. The equipment is also assumed to have a braking rate that would allow the new trains to stop from 79 mph in the same time that the existing trains now require to stop from the present 65 mph maximum speed.
- Longer train consists. Two of the present scheduled trains are assumed to be lengthened from six to eight car consists. If implemented, this recommendation would require addition of four cars to the new fleet.
- Additional trains. Two additional Metra Electric trains during the peak one hour are assumed to be operating in the peak direction. For planning purposes, it is assumed that these two additional trains would be eight car consists. If implemented, this recommendation would require addition of 16 cars to the new fleet. The two trains can be two Metra trains, one Metra train and one NICTD train, or two NICTD trains, as determined in the future.

These assumptions are considered to represent the probable future worst case operating conditions for the Metra Electric District system and, for reasons discussed above, could not be immediately implemented today. In order to implement the assumed service by 2020, the Electric Division rolling stock and fixed plant would need to be upgraded to remove constraints to increased levels of service. The required system modifications identified thus far include:

- Augmentation of the power supply system to eliminate low voltage areas.
- Modification of signal system to permit the higher operating speed.
- Lengthening of station platforms at Randolph Street, and at other key stations served by the Mainline trains.
- Improvements to the Randolph Street interlocking and track geometry to increase throughput capacity and eliminate congestion at interlocking.
- Improvements to trackage to permit additional throughput through the south end of Downtown, focusing on Van Buren Street through 11th Place.
- Improvements to track and interlocking arrangements at Kensington, to increase speeds and throughput capacity.
- Expansion of Centralized Traffic Control (CTC) to include the entire Electric Division.
- Extending other station platforms as required along the route.
- Possible joint use of the South Shore terminal trackage by both Metra and NICTD trains to permit Metra's five lower level terminal tracks to accommodate more trains. One possibility might be use of the South Shore terminal tracks for Metra's South Chicago and/or Blue Island locals.

3. ROLLING STOCK

3.1 BASIC ROLLING STOCK CONFIGURATION OPTIONS

As recommended in the Volume 2 of the study, the entire fleet of rolling stock should be replaced. The replacement rolling stock should be of modern design including AC propulsion, stainless-steel body, and up-to-date subsystems. The following replacement options for the Highliner cars were identified:

- Electric Multiple Units, Bi-Level or Single Level
  - All Units with Motive Power, Single Cars or Married Pairs
  - Two Out of Three Units with Motive Power
- Locomotive Power with Push-Pull Bi-Level Cars
  - Electric Locomotives
  - Dual Power Locomotives (DPLs)

3.2 VEHICLE OPTIONS CONSIDERING SYSTEM TYPE

The rolling stock configuration options can be expanded when considering the electrification system to be used in the future. Consistently with the system electrification voltages of 1,500 V DC, 12.5 kV AC, and 25 kV AC, the following rolling stock options are available:

- Replacement of the existing MU vehicles with new 1,500 V DC vehicles
- Replacement of the existing MU vehicles with new 12.5 kV AC vehicles
- Replacement of the existing MU vehicles with new 25 kV AC vehicles

The available options for electric locomotive include:

- Procurement of 1,500 V DC locomotives
- Procurement of 12.5 kV AC locomotives
- Procurement of 25 kV AC locomotives
- Procurement of the appropriate number of coaches.

The available options for the DPLs include:

- Procurement of 1,500 V DC and diesel DPLs
- Procurement of the appropriate number of coaches

The DPLs do not include the 12.5 kV AC or 25 kV AC options as the locomotives do not have sufficient room for transformers and rectifiers necessary for the high voltage AC operation.

In the event that Metra were to convert its electrification system to 12.5 kV AC or 25 kV AC, NICTD would have to replace its existing rolling stock with equipment operating on two voltages, 1,500 V DC and 12.5 kV AC or 1,500 V DC and 25 kV AC, depending on the Metra electrification system choice. Selection of the DC link voltage of about 1,500 V DC would minimize additional equipment required on the new rolling stock.

3.3 ELECTRIC MULTIPLE UNITS

3.3.1 Bi-Level Units

Replacement of the existing Highliner cars with modern bi-level electric multiple units (EMUs) would result in higher performance and lower maintenance costs in comparison to the existing operation. This is due to the fact that the new EMUs would feature state-of-the-art propulsion system with all subsystems of current design.

The higher performance of the new cars could justify consideration of an EMU fleet consisting of triplets. In a triplet, two of every three cars would be powered cars and one car would be a non-powered trailer car. The end powered cars would be provided with cabs and the middle trailer cars could be redesigned for higher passenger capacity. Although the triplet performance would not quite match the performance of three powered EMUs, the higher passenger carrying capability could maintain the present passenger throughput.

Introduction of the triplets would reduce fleet acquisition cost due to saving of propulsion systems on ⅓ of the cars. Also, maintenance costs would be reduced as no comprehensive, EMU-type, inspections would be needed for the trailer cars. Additionally, when cars are semi-permanently coupled the adjoining cars can be joined using articulations that provide additional passenger floor space.

The chief disadvantage of the triplets is their reduced capability to form train consists of required size. Metra would be required to operate only three and six car train consists and would lose the flexibility to operate two, four, five, seven, and eight car consists. Although Metra plans to operate eight car consists in the future, nine car consists, using triplets, would require extensive infrastructure modifications. Metra could include single or married pair cars in the fleet to meet the consist flexibility requirements. However, triplets and singles or married pairs would have to be available at each terminal to meet dispatching requirements.

Because of this disadvantage, the use of triplets will not be considered further. Replacement of the existing rolling stock with powered EMUs will be considered as one of the options in this report. In order to perform the train performance calculations, characteristics of a prototypical EMU were developed in Appendix B.

3.3.2 Single Level Units

Single level EMUs have lower seat capacity than the Highliners, but they would have faster passenger boarding and alighting, and therefore would reduce passenger station dwell time. By combining the higher performance of new AC propulsion system and the shorter station dwell times, the single level MU cars can run on a tighter schedule. This would allow more trains to operate during the rush hour and enable the passenger seat capacity of the single level EMUs to approach the capacity of the present Highliner cars.

Preliminary investigation into single level MU performance indicates that, although the improved performance of the new cars would lead to schedule improvement, the single level MU cars cannot equal the Highliner seat capacity. Even single level cars designed as triplets, with only two doors per car and articulation connections, could not mach the Highliner seat capacity. Therefore, this option will not be studied further in this report.

3.4 LOCOMOTIVE POWER WITH PUSH-PULL BI-LEVEL CARS

3.4.1 Locomotive Options

The options for push-pull service include the following motive power:

- Electric Locomotives
- Dual-Power Locomotives

3.4.2 Electric Locomotives - ALP-46

The ALP-46, manufactured by Adtranz, are high speed passenger locomotives based on a successful German design. The locomotives use AC propulsion equipment based on gate-turn-off (GTO) thyristor-controlled inverter and four traction motors. In the event that the ALP-46 locomotives are considered for use by Metra, it is recommended to replace the GTO inverters with insulated gate bi-polar transistor (IGBT) inverters. The IGBT inverters are simpler, less expensive, and more efficient than the GTO inverters. Also, IGBT-based propulsion systems exhibit high power factor with value of 0.98 possible throughout the speed range, and require less harmonic filtering. The locomotive characteristics are presented in Appendix B.

3.4.3 Dual-Power Locomotives - Genesis Series 2

The GE Genesis Series 2 locomotives are four-axle, four traction motor, high-speed, diesel-electric passenger locomotives designed for inter-city and commuter passenger service where both, third rail electric and diesel operation is required. The locomotives are equipped with an inverter-based AC propulsion system which operates either from DC supply or with the use of its diesel engine. Changeover from electric to diesel operation and from diesel to electric can be made with action initiated by the engineer while the locomotive is in motion. The locomotives include the latest in

diesel engine technology, containing a microprocessor-controlled GE Model FDL-12 diesel engine equipped with an electronic fuel injection system for fuel economy and reduced emissions. All major system of the locomotives, including the propulsion system, the head-end power system, the adhesion system and the blended dynamic braking/air brake system are microprocessor-controlled for improved performance and economy. The locomotive characteristics are shown in Appendix B.

The reliability record of the New Haven Railroad and Amtrak FL-9 DPLs built by General Motors' Electro-Motive Division (EMD) and the Metro-North P32AC-DM DPLs built by General Electric (GE) shows that the FL9s, both as new and after a group rebuild, have been troublesome. The GE locomotives have been significantly better by comparison. However, there is not sufficient experience as yet with the Long Island Railroad new DM 30s built by EMD to make final judgement. The dual-power locomotives (DPLs) would be applicable in the event that Metra wishes to extend service beyond University Park, beyond 91st Street (93rd Street when the already designed catenary system is extended), or beyond Blue Island, without electrifying.

3.4.4 Push-Pull Cars

Push-pull type Highliner cars are an attractive option because they do not require the intensive inspection required for EMU cars and their initial cost is lower than the cost of comparable EMU cars. Locomotives propel the push-pull cars at one end of the train, while the other end of the train is equipped with a cab car.

Although locomotives, such as the ALP-46, can achieve the performance comparable to EMUs, having sufficient acceleration rate, braking rate, and top speed, locomotive-hauled trains do not have the operational flexibility of EMUs. The EMU flexibility in quick train consist make up and adjustment is absolutely essential for Metra while operating within the Randolph Street station constraints.

In addition, Metra needs to consider the possible consequences of low adhesion conditions resulting due to accumulation of snow, ice, or leaves on the rails. Because tractive effort is exerted only by the locomotive, low adhesion has more serious consequences for locomotive-hauled than for EMUs.

3.5 TRAIN PERFORMANCE SIMULATIONS

Train performance simulations were performed for the rolling stock replacement options under evaluation, and the results are presented in Appendix C. The Table 3-1 shows the existing rolling stock performance, and the Table 3-2 shows the future rolling stock performance.

The simulations were performed using the Energy Management Model (EMM) already introduced in the Volume 2 of this report. The computer simulations of train operation show that new EMUs are superior in performance to the existing EMUs, the electric locomotive-hauled trains, and the DPL-hauled trains. Use of the EMUs would improve the operation along the Metra system due to higher acceleration, top speed, and faster turn around time.

Table 3-1 - Existing Rolling Stock Performance

Rolling Stock	Route	Acceleration Rate (miles/h/s)	Maximum Speed (miles/h)	Trip Time (minutes)
Bi-Level EMUs	Randolph Street to Harvey	1.0	65	38.77
	Randolph Street to Flossmoore			44.72
	Randolph Street to University Park			53.31
	Randolph Street to South Chicago			41.64
	Randolph Street to Blue Island			48.61

Table 3-2 - Future Rolling Stock Performance

Rolling Stock	Route	Acceleration Rate (miles/h/s)	Maximum Speed (miles/h)	Trip Time (minutes)
Bi-Level EMUs	Randolph Street to Harvey	2.0	79	33.90
	Randolph Street to Flossmoore			38.09
	Randolph Street to University Park			44.27
	Randolph Street to South Chicago			38.48
	Randolph Street to Blue Island			44.20
Electric Locomotive with Bi-Level Cars and Push-Pull Operation	Randolph Street to Harvey	1.5	79	35.18
	Randolph Street to Flossmoore			39.36
	Randolph Street to University Park			45.68
	Randolph Street to South Chicago			39.24
	Randolph Street to Blue Island			45.12
Dual-Power Locomotive with Bi-Level Cars and Push-Pull Operation	Randolph Street to Harvey	1.0	79	38.33
	Randolph Street to Flossmoore			43.07
	Randolph Street to University Park			50.25
	Randolph Street to South Chicago			41.15
	Randolph Street to Blue Island			47.33

3.6 ROLLING STOCK QUANTITY ESTIMATE

Based on the assumptions presented in the study, two of the presently scheduled trains will be lengthened from six to eight car consists and two additional trains, each with eight cars, would be added to the A.M. peak and P.M. peak hour schedule.

This recommendation would add 20 cars to the present fleet of 165 cars, for a total of 185 EMUs or trailers. For electric or dual-power locomotive option, it is estimated that the 185 trailers would require 42 locomotives.

3.7 COST ESTIMATES

3.7.1 General

In order to determine which of the rolling stock options under consideration is the most cost effective, capital cost, as well as operations and maintenance cost estimates were developed for the following replacement options:

- Bi-Level EMUs
- Electric Locomotives with Push-Pull Operation Using Bi-Level Cars
- Dual Power Locomotives with Push-Pull Operation Using Bi-Level Cars

In order to simplify the cost estimating effort, use of differential or "delta" pricing was used as much as possible. For example, when estimating maintenance costs of EMU and dual power locomotive-hauled trains, the maintenance costs of car body, operator's cab, doors, HVAC system, lighting, brakes, and trucks will be comparable for both types of trains and need not be carried in the evaluations. However, because of presence of diesel engine and alternator on the DPL, the additional maintenance cost of this equipment needs to be recognized.

All costs were estimated in year 2001 U.S. dollars and are presented in Appendix D.

3.7.2 Capital Costs

Based on the future expected rolling stock quantity and estimated rolling stock unit prices, total costs were developed for the EMU trains, electric locomotive-hauled trains, and DPL-hauled trains. Additionally, requirements for storage facility expansion were identified for each option and cost estimates included. Further, for the dual-power locomotive-hauled trains, cost of diesel refueling facility was estimated.

3.7.3 Operations and Maintenance Costs

The rolling stock operation and maintenance costs were evaluated for the three rolling stock replacement options under consideration and included the following costs:

- Operations Costs include the cost of train operators and support staff, as well as rolling stock energy consumption costs. These cost would not vary appreciable with the type of rolling stock used, the differences in operations cost were negligible.
- Maintenance Costs were estimated in two categories, annual maintenance costs and major maintenance costs. The annual maintenance costs include routine rolling stock maintenance

and train refueling operation. The major maintenance include rolling stock maintenance in 10 year and 20 year intervals.

3.7.4 Life Cycle Cost Estimate

Life Cycle cost estimates for each of the three rolling stock options under considerations are derived in Table 3-3 as a sum of the total capital cost and the present worth of operations and maintenance costs.

Table 3-3 -Rolling Stock Life Cycle Cost Estimate

Rolling Stock Option	Cost	Cost Estimate (millions of dollars)	Total Life Cycle Cost (millions of dollars)
Bi-Level EMUs	Capital	659	1,152
	Operations and Maintenance	493	
Electric Locomotive with Push-Pull Bi-Level Cars	Capital	666	1,133
	Operations and Maintenance	467	
Dual Power Locomotive with Push-Pull Bi-Level Cars	Capital	722	1,420
	Operations and Maintenance	698	

The total capital costs were increased by so-called add-on amounts for contractor's mobilization and demobilization, consultant's design and engineering support, construction management, agency engineering support, agency construction support, compliance with specification's general conditions, environmental assessment effort, laboratory testing allowance, field testing and commissioning, spare parts, special tools and equipment, system documentation, training, and construction contingency.

The O&M costs were estimated over 30 year period using annual inflation rate of 4%. The present worth of the O&M costs was calculated assuming annual interest rate of 8%.

The table shows that although the capital cost of EMUs is the lowest, the Electric Locomotive with Push-Pull Bi-Level Cars option is the most cost effective overall. However, despite the cost difference, the EMUs are still the preferred option over the locomotive-hauled trains due to the EMU higher acceleration rate and flexibility to quickly change consist sizes.

4. TRACTION POWER SYSTEM

4.1 SUPPLY SYSTEM CONFIGURATIONS

Three traction power system configurations were selected for evaluations in the study:

- Augmentation of the existing 1,500 V DC power system.
- Total replacement of the existing system with a new 2 x 12.5 kV AC autotransformer feed system (AF) operating at commercial frequency of 60 Hz.
- Total replacement of the existing system with a new 25 kV AC direct feed system (DF) operating at commercial frequency of 60 Hz.

Each of the configuration needs to be designed to provide sufficient electrical power to the trains. In order to verify the suitability of each system to support the higher loads anticipated in the future, a full computer load-flow simulations were performed taking into account the passenger traffic density and rolling stock operation projected for the year 2020. The simulations were performed using the Energy Management Model (EMM) already introduced in the Volume 2 of this report.

During the simulations, electrical performance of each system was evaluated to assess the traction power and distribution systems capacity. Locations and ratings of substations, tie station, paralleling stations, and switching stations were proposed. The computer output, including the system currents, voltages, power flows, and power losses was used to verify the facility locations and ratings and to confirm sizes of the overhead catenary conductors.

The existing 1,500 V DC power system is quite familiar to Metra and, therefore, will not be discussed here. The basic features of the 12.5 kV AC and 25 kV AC systems are discussed in the following sections. Each of the AC systems comprise the following subsystems:

- Traction Power Supply System including traction power substations.
- Traction Power Distribution System consisting of overhead catenary system, feeder system, switching stations, and paralleling stations.
- Traction Power Return System comprising of rails, static wire, cross-bonds, and grounding.

4.1.1 Autotransformer Feed System

4.1.1.1 AT Traction Power Supply System

The traction power supply system consists of traction power substations located at predetermined spacings along the system right-of-way, typically at a distances of about 25-35 miles. The

substations receive power directly from the local high voltage electrical power utility substations located in the proximity of the route or from transmission lines crossing or running along the alignment. Typically, the utility power input will be at 69 kV or 115 kV, but may be as high as 230 kV. Connections to the utility high voltage lines are required to ensure high supply reliability and low susceptibility to phase unbalance, harmonic distortion, and voltage flicker that may result from the addition of the highly fluctuating traction load.

Each traction power substation normally includes high voltage supply line dead-end structures, high voltage circuit breakers, high voltage disconnect switches, traction power transformers, a line up of medium voltage switchgear, and auxiliary equipment. Depending on the power utility design requirements, the substations may also contain special equipment, such as harmonic distortion filters and power factor correction equipment. Simplified diagram of autotransformer feed system is shown in Figure 4-1.

The single-phase traction power transformer primary windings are connected to two phases of the utility power system and, since power is being drawn from only two phases of a three-phase system, a certain amount of current and voltage unbalance will occur. In order to mitigate the effects of the unbalanced currents and voltages, the single-phase connections should be alternated at successive substations. Therefore, in an interconnected power utility network, the unbalanced currents and voltages will tend to balance out by the time they reach the utility generators or utility consumer motors.

The high voltage utility power is transformed to the feeder/catenary distribution voltage of 25 kV by traction power transformers. There will be two equally sized transformers at each substation to allow continuous system feeding in the event of outage of one utility feeder, transformer, or other item of high voltage equipment. One of the transformer secondary terminals is connected to the feeder and the other terminal to the catenary. The secondary winding of the transformers is provided with a center tap, which is tied to the rail/static wire/ground return system. Since this connection results in 12.5 kV between the feeder and the return system and 12.5 kV between catenary and the return system, the system is known as a 2 x 12.5 kV system. At the substation locations, a phase break will be installed in each catenary to electrically separate the northen feeding portion from the southern feeding portion.

4.1.1.2 AT Traction Power Distribution System

From the traction power substations power is distributed along the system route by the feeder/catenary system. For a high density operation in multiple-track territory, two feeders are recommended to provide for redundancy in the system. Along the open route, the feeders consist of bare conductors attached to the catenary structures with brackets and insulators. In the tunnels and at overpass bridges, it is probable that insulated cables would have to be used for the feeders due to the inadequacy of electrical clearances. The catenary system consists of a messenger wire and a contact wire. The contact wire is suspended from the messenger wire by the means of hangers. In single-track and double-track segments of the route, the conductors are supported and registered from poles and other overhead structures by means of cantilevers. In three-track and four-track areas, the catenary system will be supported from portal structures or headspans.

The ratio of the distribution voltage (feeder-to-catenary) and the traction voltage (catenary-to-rail) depends on the autotransformer winding ratio. Systems with 2:1 and 3:1 autotransformer winding ratio have been successfully used for many years in Europe, Japan, and United States. For example, for the 2 x 12.5 kV system a 2:1 autotransformer ratio is used. The catenary and feeder conductors are connected to the 25 kV primary windings of the autotransformers. The 12.5 kV secondary terminals are connected to the catenary and the rail/ground return system, thereby providing the 12.5 kV electrification voltage between the catenary and rails. In the United States, the Southeastern Pennsylvania Transportation Authority (SEPTA) has been using since the early 1900's a system with 3:1 ratio, i.e., 36 kV autotransformer primary and 12 kV autotransformer secondary. The catenary and feeder conductors are connected to the 36 kV primary windings of the autotransformers. The 12 kV secondary terminals are connected to the catenary and the rail/ground return system, thereby providing the 12 kV electrification voltage between the catenary and rails.

In order to transform the 25 kV between the catenary and feeder to a traction power level of 12.5 kV and provide additional sectioning of the catenary and feeder systems, paralleling stations are installed along the route at a spacing of 6-8 miles. Each paralleling station is equipped with medium voltage switchgear configured to include catenary circuit breakers, feeder circuit breakers and autotransformer circuit breakers. Since the phase on each side of catenary section break is the same, bus tie circuit breakers are not required. The catenary and feeder circuit breakers also enable sections of the distribution system to be disconnected and de-energized following a fault or for maintenance. The paralleling stations permit paralleling of the catenary and feeder systems in multiple-track areas and by this paralleling decrease the system impedance between substations and trains, provide for better current sharing between conductors of adjacent tracks, and improve catenary and feeder fault detection.

At approximately the midpoint between substations, phase breaks are installed in the overhead catenary system to electrically separate adjacent sections of the system operating at different phases. In order to provide for the catenary and feeder system switching in the event of a substation outage, protect the system against faults, and parallel the system in multiple-track areas, switching stations are provided at these locations. The switching stations also act as paralleling stations and provide 12.5 kV traction voltage to the catenary system via autotransformers. Each switching station is equipped with medium voltage switchgear cond to include catenary circuit breakers on each side of the phase break, feeder circuit breakers, and catenary and feeder bus tie circuit breakers. The catenary and feeder breakers are normally closed and the bus tie circuit breakers are normally open. The purpose of the bus tie breakers is to connect the adjacent sections of the distribution system in the event of a substation outage. Similar to the paralleling stations, the switching station paralleling of the catenary and feeder systems in multiple-track areas benefits the system impedance value, current sharing, and catenary fault detection.

4.1.1.3 AT Traction Power Return System

The trains collect propulsion power from the overhead catenary system, using pantographs, and return the current back to the substations via the traction power return system. The traction power return system consists of the running rails, an overhead static wire, and the ground itself.

The running rails are cross-bonded at impedance bonds, and the cross-bonds are grounded. The catenary system supporting structures are connected by an overhead static wire, which is also grounded at frequent intervals. The result is that a portion of the return current flows in the rails, the static wire, and the ground.

The purpose of this design is to provide as low an impedance return system as possible to limit voltage rise along the rails (rail-to-ground potentials) and to improve catenary fault detection by creating sufficiently high short-circuit current.

4.1.2 Direct Feed System

4.1.2.1 DF Traction Power Supply System

The traction power supply system consists of traction power substations located at predetermined spacings along the system right-of-way, typically at distances of about 15-20 miles. The substations receive power directly from the local high voltage electrical power utility substations located in the proximity of the route or from transmission lines crossing or running along the alignment. Typically, the utility power input will be at 69 kV or 115 kV but may be as high as 230 kV. Connections to the utility high voltage lines are required to ensure high supply reliability and low susceptibility to phase unbalance, harmonic distortion, and voltage flicker that may result from the addition of the highly fluctuating single-phase traction load.

Each traction power substation normally includes high voltage supply line dead-end structures, high voltage circuit breakers, high voltage disconnect switches, traction power transformers, a line up of medium voltage switchgear, and auxiliary equipment. Depending on the power utility design requirements, the substations may also contain special equipment, such as harmonic distortion filters and power factor correction equipment. Simplified diagram of direct feed system is shown in Figure 4-2.

The single-phase traction power transformer primary windings are connected to two phases of the utility power system and, since power is being drawn from only two phases of a three-phase system, a certain amount of current and voltage unbalance will occur. In order to mitigate the effects of the unbalanced currents and voltages, the phase-to-phase connections should be alternated at successive substations. Therefore, in an interconnected power utility network, the unbalanced currents and voltages will tend to balance out by the time they reach the utility generators or utility consumer motors.

The high voltage utility power is transformed to the traction power distribution system voltage of 25 kV by traction power transformers. There will be two equally sized transformers at each substation to allow continuous system feeding in the event of outage of one utility feeder, transformer, or other item of high voltage equipment. One end of the transformer secondary winding feeds the catenary system through the medium voltage switchgear and the other end is connected to the rail/static wire/ground return system. At the substation locations, a phase break will be installed in each overhead catenary to electrically separate the northen feeding portion from the southern feeding portion.

4.1.2.2 DF Traction Power Distribution System

From the traction power substations, power is distributed along the system route by a simple overhead catenary system consisting of a messenger wire and a contact wire. The contact wire is suspended from the messenger wire by the means of hangers. In single-track and double-track segments of the route, the conductors are supported and registered from poles and other overhead structures by means of cantilevers. In three-track and four-track areas, the catenary system will be supported from portal structures or headspans.

At approximately the midpoint between substations, phase breaks are installed in the overhead catenary system to electrically separate adjacent sections of the system operating at different phases. In order to provide for the catenary system switching in the event of a substation outage, protect the catenary system against faults, and parallel the catenary system in multiple-track areas, switching stations are provided at these locations. Each switching station is equipped with medium voltage switchgear configured to include catenary circuit breakers on each side of the phase break and a bus tie circuit breaker. The catenary breakers are normally closed and the bus tie circuit breaker is normally open. The purpose of the bus tie breaker is to connect the adjacent sections of the distribution system in the event of a substation outage. The catenary circuit breakers also enable sections of the distribution system to be disconnected and de-energized following a fault or for maintenance. The switching stations permit paralleling of the catenary systems in multiple-track areas and by this paralleling decrease the system impedance between substations and trains, provide for better current sharing between conductors of adjacent tracks, and improve catenary fault detection.

At the end of electrified line, the catenary system may be equipped with an end-of-line paralleling station. To protect the catenary system against faults, each paralleling station is equipped with medium voltage switchgear. However, because the voltage on either side of the paralleling station is of the same phase and magnitude, there is no need for a bus tie circuit breaker. Similar to the switching stations, the end-of-line paralleling of the catenary systems in multiple-track areas benefits the system impedance value, current sharing, and catenary fault detection.

4.1.2.3 DF Traction Power Return System

The trains collect propulsion power from the overhead catenary system, using pantographs, and return the current back to the substations via a traction power return system. The traction power return system consists of the running rails, an overhead static wire, and the ground itself.

The running rails are cross-bonded at impedance bonds, and the cross-bonds are grounded. The catenary system supporting structures are connected by an overhead static wire, which is also grounded at frequent intervals. The result is that a portion of the return current flows in the rails, the static wire, and the ground.

The purpose of this design is to provide as low an impedance return system as possible to limit voltage rise along the rails (rail-to-ground potentials) and to improve catenary fault detection by creating sufficiently high short-circuit current.

4.2 UTILITY COORDINATION

Early in the Study, a contact with Commonwealth Edison, the local power utility company, was initiated to discuss the following issues pertaining to electrification.

4.2.1 Rating of Transmission and Distribution Lines

New 1,500 V DC system traction power substations would be supplied from the 12.47 kV AC distribution system as at present. However, for 12.5 kV AC and 25 kV AC electrification, priority needs to be given to high voltage systems in the range of voltages from 69 kV to 230 kV. Below this voltage range the utility system does not often have sufficient fault level for traction power substation supply and above this range, the cost of substation equipment high voltage insulation is prohibitive.

4.2.2 Location of the Utility Distribution Network

Medium voltage distribution system operating at 12.47 kV is readily available at most locations and the traction power substation power supply can be provided relatively inexpensively.

4.2.3 Location of the Utility Transmission Network

Commonwealth Edison was requested to provide locations of their high voltage substations and transmission lines. When received, the locations were superimposed onto the Metra Electric District system map to determine locations where the utility substations are in the vicinity of the railroad and where the transmission lines either cross or run alongside the railroad. The object of this effort was to locate potential sites for the new traction power substations as close as possible to the utility facilities and to the railroad. Such locations would minimize costly transmission line runs and excessive substation to catenary feeder lengths.

The Commonwealth Edison 138 kV lines are crossing the tracks at the following locations:

- 75th Street, approximate milepost 9.3. A double-circuit transmission line crosses the railroad. A potentially suitable site for traction power substation has been identified on the west side of the tracks at crossing of South Chicago and Woodlawn Streets.
- 127th Street, approximate milepost 16.0. A double-circuit transmission line crosses the railroad and terminates at Commonwealth Edison substation on the west side of the tracks. A potentially suitable site for traction power substation has been identified adjacent to the Commonwealth Edison substation on the west side of the tracks.
- 130th Street, approximate milepost 16.3. A double-circuit transmission line from the 127th Street substation runs along the railroad and crosses the tracks at 130th Street. A potentially suitable site for traction power substation appears to exist in the railroad vicinity.
- 138th Street, approximate milepost 17.4. Three double-circuit transmission lines cross the railroad. A large plot of land, which would be suitable for traction power substation, exists on the west side of the tracks.

- 161st Street, approximate milepost 20.9. Two double-circuit transmission lines cross the railroad. A large plot of land, which would be suitable for traction power substation, exists on the west side of the tracks.
- 219th Street, approximate milepost 28.8. A double-circuit transmission line crosses the railroad. Although the transmission line right-of-way is relatively wide, and it is possible that a suitable site for traction power substation might be found, building a high voltage facility in this residential area would be difficult.

4.2.4 Current and Voltage Unbalance

4.2.4.1 Origin of Unbalance

Normally, the three-phase utility transmission system is essentially balanced. The vectors of voltages and currents in all phases are of equal magnitude and spaced 120 electrical degrees apart. When a phase-to-phase load is connected to such a balanced system, the currents cause unequal voltage drops to occur in different phases, and this causes an unbalance in the utility network voltages. Unbalanced voltages cause a flow of negative sequence currents in three-phase equipment connected to the utility network. The voltage and current unbalance throughout the utility network can be calculated by using a specially developed software.

4.2.4.2 Unbalance Effects

In the case of rotating plant such as utility company power generators and utility consumer three-phase induction and synchronous motors, these negative sequence currents induce currents in the machine rotors at double the system frequency and produce additional heating in the rotor forgings, wedges, damper windings, and retaining rings. The amount of negative sequence currents which the rotating plant can absorb without overheating is dependent on the machine design and the length of time for which the machine is exposed to the unbalanced currents. These unbalance currents produce additional heating in the machine rotors.

4.2.4.3 Unbalance Limits

ANSI C50.13 and NEMA MG-1 standards cover continuous and short time negative sequence current capability for cylindrical-rotor synchronous generators. Rotating machines should withstand the effects of continuous negative sequence current of 5-10 % of rated stator current without injury. On a short time basis, the magnitude of product I_2^2 t should not exceed 40 for motors, hydraulic turbine or engine driven generators, 30 for indirectly cooled turbine generators, 10 for directly cooled generators up to 800 MVA and 5 for some very large machines, e.g. 1,600 MVA. I_2 is the negative sequence current in per unit of machine rated current and t is time in seconds.

4.2.4.4 Protection Against Unbalance

Negative phase sequence relays are usually installed on generators and large motors to protect them against high values of unbalance. Relays with two current and time settings can be used, one setting given an alarm, the other tripping the machine.

4.2.4.5 Unbalance Control

The voltage and current unbalance on the utility system can be limited by allocating power feeding to alternate phases of the supply system at successive substations or by attempting to load all three phases using two single-phase transformers, three-phase to two-phase transformers or three-phase transformers at traction power substations. Where sufficient balancing cannot be achieved by these methods, static balancing equipment (resistor, reactor, and capacitor network) or rotary balancing equipment (synchronous condensers or induction motors) can be used.

4.2.5 Current and Voltage Harmonic Distortion

4.2.5.1 Origin of Harmonic Distortion

Power electronics control equipment used on board locomotives (thyristors in particular, IGBT to lesser degree) cause the traction current to be non-sinusoidal in form. The typical current waveform of thyristor-controlled rolling stock resembles a square wave and is composed of a current at fundamental and harmonic frequencies. The harmonic currents cause voltage drops in the traction power system which distort the utility system voltages and, in turn, the distorted voltages cause a flow of harmonic currents in the equipment connected to the system.

4.2.5.2 Harmonic Distortion Effects

The presence of harmonics increases the RMS value of the system voltages and currents and thus causes a larger loading of the equipment. The harmonic currents, being unbalanced, produce positive and negative sequence component magnetic fields in rotating plant equipment. These fields cause an increase in the iron losses due to eddy currents and additional copper losses in the stators and rotors. Machine heating is increased as a result of the higher losses.

The reactance of capacitors decreases as frequency of the harmonics increases. Hence, the higher the frequency of applied voltage, the larger the current that flows through capacitors, and the greater the heat generated in their dielectric. Shunt capacitors used for power factor correction are a particular example where damage due to overheating can be caused by harmonics in the utility system.

Harmonic currents in the catenary system may also induce noise in paralleling control, telecommunication, and signal circuits. In systems with appreciable susceptance, a particular harmonic may coincide with the natural frequency of the system. In such cases, the utility system will resonate and additional distorted currents and voltages will be produced.

4.2.5.3 Harmonic Distortion Limits

The IEEE Std. 518 provides maximum permissible limits on distortion. In previous studies conducted for a number of utilities concerned with railroad electrification in the USA, a total harmonic voltage distortion limit of 3 percent and a single harmonic voltage distortion limit of 1 percent were chosen as appropriate in the regional area concerned.

4.2.5.4 Harmonic Distortion Control

Harmonic current and voltage distortion can be controlled by the application of filters. Filters usually consist of a series combination of reactors and capacitors connected to the traction power system. Several conditions should be satisfied when designing filtering equipment. Filter component rating must be higher than the theoretical requirements to allow for the effect of harmonic components and resonant frequency currents and voltages.

Filters should be of low overall impedance in comparison to the utility system to so that adequate shunt is provided for the harmonics. The values for reactors and capacitors should be selected so that excessive voltages are not created in the filter during resonant conditions. The resistance of the filter in comparison to its reactance should be low to ensure high frequency selectivity, thus preventing loading of the filter with power at the fundamental frequency.

4.2.6 Power Factor Correction

A low power factor causes a larger power flow due to the increased reactive component of the current. Thus voltage regulation in the utility supply transmission lines and the catenary system is increased and the equipment may become overloaded.

The power factor of a typical thyristor-controlled rolling stock is low at low speeds, but since the locomotive traction power demand is also low, the effect on the utility system is not significant. As the power demand increases at higher speeds, the power factor improves and the average value is then comparable to the power factor of other industrial loads supplied by the utility system. Modern rolling stock drive systems, such as those using IGBT technology, can be designed to exhibit nearly unity power factor throughout the rolling stock speed range.

4.2.7 Voltage Flicker

Railroad traction currents consist of both slowly and rapidly changing loads. These loads produce long-time and short-time voltage regulation. Long-time regulation decreases the utility voltage, may cause higher current loading of other consumer rotating plants, and may cause more frequent operation of utility voltage regulators and transformer on-load tap changers, with consequential increase in maintenance requirements. Short time regulation may cause some incidence of objectionable light flicker at nearby consumers premises. The measure of short-time regulation acceptable by utilities depends on the magnitude and number of voltage dips which occur. Some utilities allow a maximum level of fluctuation on the worst phase as given in IEEE Standard 141-1976 by the border line of visibility of flicker curve.

When selecting a utility feed point for supply of traction power substations, the available fault level should be determined and a load flow study may need to be performed to ascertain minimum voltage levels due to the projected traction loads. As the traction power substations are generally connected to high voltage utility systems, the available fault levels will generally be sufficient to avoid undesirable effects due to either type of regulation.

4.3 ELECTRIFICATION SYSTEM AND VOLTAGE

Selection of electrification voltage has a major impact on the system cost. The 25 kV AC center feed system has the advantage over the 12.5 kV AC center feed system in that it affords longer substation spacings with corresponding savings in electrical equipment and real estate. However, these savings have to be balanced by any civil modifications, if required, to achieve the required clearances for electrification at the higher voltage.

The 12.5 kV AC autotransformer feed system has comparable substation spacings as the 25 kV AC center feed system. The civil modifications for the 12.5 kV AC autotransformer feed system would be comparable to the civil modifications required for the 12.5 kV AC center feed system.

Modern electrification systems in this country, such as the NJ Transit North Jersey Coast Line and the Amtrak Northend New Haven to Boston project, were designed using commercially available 60 Hz power supplied from local utility network. Since we do not believe that there is a compelling reason to use 25 Hz, only power supply at 60 Hz will be considered in this study.

4.4 LOCATIONS OF TRACTION POWER SUPPLY FACILITIES

As already stated, the locations and rating of the traction power system substations, and the locations of tie stations, paralleling stations, and switching stations were based on the computer-aided load flow simulations. The simulations were performed for the following systems:

- Augmentation of the Existing 1,500 V DC Power System
- New 12.5 kV AC System
- New 25 kV AC System

All facilities were located to obtain a satisfactory voltage profile along the system. The voltage profile is the major indicator of the overall traction power system and train performance. Under normal operating conditions, i.e., all systems in service, the system voltage should not drop below the Normal Lower Voltage Limit as defined in Appendix B, Volume 2. The voltage profiles were plotted for each simulation as voltage versus distance scatter charts, where each point on the chart indicates a voltage at the train pantograph at one snapshot of time. The computer input data are included in Appendix E and the output data are presented in Appendix F.

4.4.1 1,500 V DC Electrification System

The voltage profile of the 1,500 V DC traction power system is shown in Figure 4-3 assuming new EMUs and the traffic density envisaged at 2020. Under normal operating conditions, i.e., all systems in service, the simulation resulted in the minimum pantograph voltage levels above the Normal Lower Voltage Limit of 1,200 V DC as defined in Appendix B, Volume 2. Expanded scale voltage profile is presented in Figure F-1, Appendix F.

The simulation resulted in the substation and tie station locations shown in Table 4-1.

Table 4-1 - Locations of Traction Power Facilities - 1,500 V DC System

Name	Facility	Milepost	Substation Spacing (miles)	Substation Spacing (miles)
Beginning of Line		0.00	0.50	
Jackson Blvd.	Substation	0.50		1.32
16th Street	Substation	1.82	1.21	
22nd/23rd Street	*Substation*	3.03		3.01
39th Street	**Tie Station**	4.59		
51st Street	**Substation**	6.04	1.46	
59th Street	**Substation**	7.50		0.99
Brookdale	Substation	8.49	4.56	
95th Street	Tie Station	11.79		
103rd Street	*Substation*	13.05		1.58
Front Avenue	Substation	14.63	3.05	
Wildwood	**Tie Station**	15.97		
Riverdale	*Substation*	17.68		1.39
144th Street	**Tie Station**	18.35		
147th Street	**Substation**	19.07	1.13	
Harvey	Substation	20.20		3.25
171st Street	Tie Station	22.34		
Homewood	*Substation*	23.45	2.39	
Vollmer	Substation	25.84		2.74
Olympia Fields	**Tie Station**	26.70		
Matteson	Substation	28.58	2.59	
University Park	Substation	31.17		0.23
End of Line		31.40		

The facilities printed in *italics* in Table 4-1 are the additional substations required to operate the existing rolling stock at 79 mph with field-weakening enabled as analyzed in Task 2. The facilities printed in **bold** in Table 4-1 are the additional substations and tie stations required to operate the new rolling stock and the additional trains projected to operate in the year 2020.

4.4.2 12.5 kV AC Electrification System

The voltage profile of the 12.5 kV AC traction power system is shown in Figure 4-4 assuming new EMUs and the traffic density envisaged at 2020. Under normal operating conditions, i.e., all systems in service, the simulation resulted in the minimum pantograph voltage levels above the Normal

Lower Voltage Limit of 10 kV AC as defined in Appendix B, Volume 2. Expanded scale voltage profile is presented in Figure F-2, Appendix F.

The simulation resulted in the substation, paralleling station, and switching station locations shown in Table 4-2.

Table 4-2 - Locations of Traction Power Facilities - 12.5 kV AC System

Facility Number	Substations	Paralleling Stations	Switching Stations	Stationing (miles)	Substation Spacings (miles)	
Beginning of System				0.00		
1		Paralleling Station 1		1.20		9.30
2	Substation 1			9.30		
3			Switching Station 1	14.20	11.60	
4	Substation 2			20.90		
5		Paralleling Station 2		26.90		10.50
End of System				31.40		

4.4.3 25 kV AC Electrification System

The voltage profile of the 25 kV AC traction power system is shown in Figure 4-5 assuming new EMUs and the traffic density envisaged at 2020. Under normal operating conditions, i.e., all systems in service, the simulation resulted in the minimum pantograph voltage levels above the Normal Lower Voltage Limit of 20 kV AC as defined in Appendix B, Volume 2. Expanded scale voltage profile is presented in Figure F-3, Appendix F.

The simulation resulted in the substation, paralleling station, and switching station locations shown in Table 4-3.

Table 4-3 - Locations of Traction Power Facilities - 25 kV AC System

Facility Number	Substations	Paralleling Stations	Switching Stations	Stationing (miles)	Substation Spacings (miles)	
Beginning of System				0.00		
1		Paralleling Station 1		1.20		9.30
2	Substation 1			9.30		
3			Switching Station 1	14.20	11.60	
4	Substation 2			20.90		
5		Paralleling Station 2		26.90		10.50
End of System				31.40		

4.5 SUBSTATION RATINGS

For an electrified system under study, the program will output power demands for each individual substation, and these results will also be summarized as power demands and energy consumption on system wide basis. Power demand results were calculated over several intervals in Appendix F to derive substation continuous and overload ratings and provide input to operation cost estimate in accordance with the billing interval used by the power utility. Further, standardization of design, emergency feeding conditions, unusual operating conditions, and spare capacity of substation equipment were taken into account in selection of the equipment rating to permit future increases in train consist size or in the number of trains in operation. Again, the evaluations were performed for the following systems:

- Augmentation of the Existing 1,500 V DC Power System
- New 12.5 kV AC System
- New 25 kV AC System

The computer input data are included in Appendix E and the output data in Appendix F.

4.5.1 1,500 V DC Electrification System

Simulation of the existing 1,500 V DC traction power system indicated that the existing system should be augmented by seven additional substations and five additional tie stations. The ratings of the new facilities are shown in Table 4-4.

Table 4-4 - Rating of New Traction Power System Facilities - 1,500 V DC System

Substation Names	Tie Station Names	Number of Tracks	Number of Transformer/Rectifiers	Transformer Rating (MVA)	Total Station Capability (MVA)
22nd/23rd Street		4	1	2	2
	39th Street	4			0
51st Street		4	1	2	2
59th Street		4	1	2	2
103rd Street		4	1	2	2
	Wildwood	2			0
Riverdale		2	1	2	2
	144th Street	2			0
147th Street		2	1	2	2
	171st Street	2			0
Homewood		2	1	2	2
	Olympia Fields	2			0

4.5.2 12.5 kV AC Electrification System

Simulation of the new 12.5 kV AC traction power system resulted in requirement for two substations, two paralleling stations and one switching station. The ratings of the new facilities are shown in Table 4-5.

Table 4-5 - Rating of Traction Power System Facilities - 12.5 kV AC System

Substations	Paralleling Stations	Switching Stations	Number of Tracks	Number of Transformers or Auto-transformers	Transformer or Auto-transformer Rating (MVA)	Total Station Capability (MVA)
	Paralleling Station 1		4	1	10	10
Substation 1			4	2	15	30
		Switching Station 1	4/3	2	10	20
Substation 2			2	2	15	30
	Paralleling Station 2		2	1	10	10

4.5.3 25 kV AC Electrification System

Simulation of the new 12.5 kV AC traction power system resulted in requirement for two substations, two paralleling stations and one switching station. The ratings of the new facilities are shown in Table 4-6.

Table 4-6 - Rating of Traction Power Facilities - 25 kV AC System

Substations	Paralleling Stations	Switching Stations	Number of Tracks	Number of Trans-formers	Transformer Rating (MVA)	Total Substation Capability (MVA)
	Paralleling Station 1		4			
Substation 1			4	2	15	30
		Switching Station 1	4/3			
Substation 2			2	2	15	30
	Paralleling Station 2		2			

4.6 REGENERATION

Thus far, the EMM program simulations were performed without the vehicle regeneration. Regenerative braking reduces voltage sags and also reduces power demand and energy costs. The degree to which these benefits can be realized depends on the system configuration, operating headways and train braking patterns.

In order to predict the potential energy savings due to regeneration, additional computer simulations were performed with the rolling stock regeneration turned on. The results of the simulations are summarized in Table 4-7.

Table 4-7 - Energy Savings due to Regeneration

Electrification Voltage	Vehicle Regeneration Status	Energy Consumed (kWh)	Energy Saving Due to Regeneration	
			(kWh)	(%)
1,500 V DC System	No Regeneration	29,812	5,415	18.2
	Regeneration On	24,397		
12.5 kV AC System	No Regeneration	29,546	11,472	38.8
	Regeneration On	18,074		
25 kV AC System	No Regeneration	28,977	11,405	39.4
	Regeneration On	17,572		

Table 4-7 projects the energy consumption for the ultimate operation of commuter trains in 2020 and, therefore, shows relatively high energy savings[1], especially for the AC electrification systems. The major contributing factors to the high energy recovery are:

- Wide substation spacings enable a large number of trains to be operating in continuous sections.
- Close passenger station spacings on the Metra Electric District system and the resultant frequent train acceleration and deceleration.

These factors offer opportunities for frequent power exchanges between trains as trains accelerate and brake.

4.7 NORMAL AND EMERGENCY SYSTEM OPERATION

During normal operation of the power system, *i.e.*, when all substations are in service, each traction power transformer is feeding its own section of track. During a transformer outage, continuity of supply to that section of track is achieved by immediate closing of the substation bus-tie circuit breaker. The remaining transformer then feeds both sections of system.

In the unlikely event of an entire substation failure, continuity of supply would be maintained by the remaining substation. The substations must be capable of supplying their own sections of the system as well as a part of the adjacent sections previously supplied with the now outaged substation. This is facilitated at switching stations situated near the midpoint between the feeding substations. During

[1] Similarly high energy savings have been recently described by Bernd Glasauer in **International Railway Journal**, IRJ Siemens Special Supplement, distributed at the UITP Congress & City Transport 2001, London, May 20-25, 2001.

a substation outage, the normally opened switching station and the outaged substation bus-tie breakers are closed, thus extending the supply area of the substation.

4.8 CRITICAL ELECTRIFICATION SYSTEM COMPONENTS

The critical components for each alternative that must be in place for the particular system implementation usually include long-lead procurement items and include the following substation equipment:

- High voltage circuit breakers and disconnect switches.
- Traction power transformers.
- Medium voltage switchgear.

The necessary safety equipment include the following:

- Special multi-zone distance protective relays to clear catenary system faults.
- Surge arresters for application at substations and low clearance bridges.
- Substation grounding of equipment to maintain safe step and touch voltages for substation maintenance personnel and safe rail-to-ground voltages to prevent shock to passengers.

Modern propulsion equipment introduces relatively low level of harmonics, and therefore, harmonic filters to limit distortion of utility and traction voltages and currents are usually not required nowadays. Similarly, the power factor of modern rolling stock is nearly unity throughout the speed range, and wayside power factor correction equipment is usually not required.

4.9 SYSTEM CONVERSION AND COORDINATION WITH NICTD

In the event that Metra would convert its 1,500 V DC electrification system to either 12.5 kV AC or 25 kV AC system, a significant coordination effort would be required with NICTD regarding their Chicago, South Shore and South Bend (CSS & SB) service. This coordination would involve the following options:

- Conversion of NICTD's existing cars to dual power depending on the Metra electrification system. The cars' dual power would be:
  - 1,500 V DC and 12.5 kV AC
  - 1,500 V DC and 25 kV AC
- Complete replacement of the cars with the appropriate dual power propulsion system
- NICTD's system re-electrification with system using the same voltage as Metra

Needless to say that all of the above options are quite expensive. Additionally, considering the service disruption that would inevitably result from implementing a new electrification system, the conversion from the existing DC system to a new AC system needs to be carefully evaluated.

Assuming that there were to be a change to AC electrification and a simultaneous replacement of rolling stock, the following issues would need to be addressed:

- Working out an arrangement with NICTD's to accommodate conversion of their cars to dual power or their system to AC electrification. The NICTD cars are not due for replacement as yet.
- Keeping the entire existing MU fleet serviceable right up to the day of the changeover.
- Providing an AC electrified test track to permit testing the new MU cars.
- Depending on the conversion approach, it might be required to maintain the entire new fleet ready to go into operation by the changeover date, with little or no opportunity to work the cars into service gradually.
- Finding enough storage tracks to accommodate a double fleet.

The project phasing would be driven to a large degree by the vehicle conversion effort, and therefore, compatibility with the traction power supply system conversion must be given consideration in the development of the conversion schedule. Project schedules would need to be developed showing when the locomotive and MU train conversion work should be started for the most cost effective project completion.

Conversion of the existing 1,500 V DC electrification to 12.5 kV AC or 25 kV AC system could be achieved by the following means:

- Converting two tracks to the new system between Randolph Street and Kensington and one track from Kensington to University Park first. Subsequently, the remaining tracks can be converted. The advantage of this approach is continuing operation with the existing electrification system and vehicles during conversion on at least part of the system. The disadvantage is the requirement for new rolling stock capable of operation on the converted system and the reduced passenger operation capability on the existing system while part of the system is being converted.
- Converting all tracks to the new system section by section. The advantage is that the system will be converted step by step in an orderly fashion The disadvantage is that prior to conversion of the first section to the new system, all vehicles, existing and new, need to be converted to be operational on both systems.
- Electrifying the presently non-electrified tracks and moving the express trains to those tracks. Subsequently, two of the electric district tracks could be taken out of service for conversion. For example, from Roosevelt Road (11th Street) to beyond Kensington, the IC used to have four tracks in addition to the electric line - two for intercity passenger and two for freight.

5. CATENARY SYSTEM UPGRADE

5.1 CATENARY SYSTEM CONFIGURATIONS

5.1.1 Catenary System Alternatives

Depending on the type of traction power supply system finally selected, the catenary system must have the appropriate insulation level, and the conductors must be of adequate size to carry the required currents.

The existing system can be described as a 1,500 V DC system with relatively heavy traction currents when compared to the optional 12.5 kV AC and 25 kV AC high voltage systems, which would be characterized as medium to low current systems. Upgrading to the high voltage systems would, therefore, allow for some down sizing of the existing conductors. To support these conductors, the existing structures could be retained, repaired, or modified. Alternatively new structures could be installed at additional expense. At the same time, opportunity should also be taken to replace the existing fixed-termination (FT) system with auto-tensioned (AT) system.

5.1.2 Catenary System Reconstruction Constraints

For Metra to maintain a train service during the period of the catenary system upgrade project, it would be necessary for the electric trains to continue to operate while one track, at a time, is taken out of service for the upgrade work. This, therefore, is the basis of the work plan upon which the cost estimates have been developed.

5.2 SHORT TERM UPGRADE

Replacement of structures does not need to be associated with upgrade of voltage or introduction of auto-tensioning. Since auto-tensioned system has significant operations benefits over the fixed-termination system, the fixed-termination system option for the existing system upgrade has not been studied further. Therefore, the number of options for the short term upgrade include:

- Re-tensioning of the existing 1,500 V DC catenary system using the existing structures.
- Provision of 12.5 kV AC or 25 kV AC auto-tensioned catenary using a simple catenary configuration and lightweight conductors.

In the event that an AC electrification system is selected, there will be a need for a voltage change-over stage. The voltage of the system cannot be increased before all the catenary insulators have been uprated. The conductors cannot be replaced with lightweight conductors until the voltage has

been raised. Since these are apparently mutually exclusive requirements, some interim operating traction power feeding plan must be introduced during the upgrade work. One possibility is temporary paralleling the catenaries of pairs of adjacent tracks to provide more copper cross-section.

5.3 LONG TERM UPGRADE

5.3.1 New Structures

The most practical way to replace existing structures is to install new portal structures over the top of the existing catenaries onto new foundations. Later, each of the catenaries can be independently transferred from the old supports to the new supports, one track at a time and one structure at a time. Each catenary would be re-hangered during the same track outage. This procedure results in minimal impact on train operations. To achieve the conductor transfer from the existing to new structures most easily, the catenary system should be auto-tensioned, so that the conductor tensions are not affected. Therefore, the structure upgrades should be deferred until the catenary is upgraded to auto-tensioned system. The new structures would be lighter than they would have been with fixed-termination equipment because auto-tensioned system results in lower conductor tensions and lower radial loads than fixed-termination system.

5.3.2 Auto-Tensioning

From a catenary system viewpoint, investment in auto-tensioning has a long-term cost benefit, since it eliminates the need for the track possessions which are regularly required for the re-tensioning of fixed-termination equipment. This is a significant advantage since the growth in passenger traffic and the corresponding expansion in the train schedule, would reduce the length or time of track outages required for maintenance.

As already mentioned in the Volume 2 of this Study, the auto-tensioned system is the universally preferred choice for tensioning from a pantograph/current collection viewpoint. When seen in the context of the improved commutation for the train pantographs, avoiding future need for re-tensioning, and facilitating structure change-out, increased investment in the auto-tensioned catenary system has both short-term and long-term operations and cost-benefits.

5.4 CATENARY SYSTEM CONDUCTOR SIZES

Sizes of the overhead conductors are selected so that the maximum conductor temperatures, under the most onerous condition of ambient temperature and train loading, do not exceed manufacturer's recommended values. For electrification systems using the AC voltages of 12.5 kV AC and 25 kV AC, the overhead conductors may be expected to be smaller than for the 1,500 V DC voltage. The smaller conductors will exert lower conductor weight, ice loadings, and wind loadings onto the supporting structures and this will translate to lighter more-economic structures and foundations as well as improved environmental impact.

Approximate ampacity values of catenary conductors are obtained using the procedure and the table published in the AREMA Manual for Railway Engineering[2]. The ampacities are calculated base on the following conditions:

- Ambient air temperature: 100°F, (37.8°C) under sunny condition
- Conductor operating temperature: 167°F, (75°C)
- Emissivity: 0.5
- Wind velocity: 2 ft/sec, (0.61 m/s)
- Contact wire wear: 30%

Approximate current carrying capacity of the proposed 12.5 kV AC autotransformer feed distribution system is estimated in Table 5-1.

Table 5-1 - Distribution System Conductor Configuration - Autotransformer Feed System

Conductor	Number of Conductors	Size	Material	Approximate Ampacity (A)
Feeder wire	1	350 MCM Stranded	H.D. Copper	670
			Total Ampacity of Feeder Wire	**670**
Messenger Wire	1	4/0 AWG Stranded	H.D. Copper	480
Contact Wire	1	4/0 AWG Grooved	H.D. Copper	390
			Total Ampacity of Messenger and Contact Wires	**870**

Approximate current carrying capacity of the proposed 25 kV AC direct feed distribution systems is estimated in Table 5-2.

Table 5-2 - Distribution System Conductor Configuration - Direct Feed System

Conductor	Number of Conductors	Size	Material	Approximate Ampacity (A)
Messenger Wire	1	4/0 AWG	Hard Drawn Copper	480
Contact Wire	1	4/0 AWG	Hard Drawn Copper	390
			Total Ampacity	**870**

5.5 AUTO-TENSIONED CATENARY SYSTEM

Auto-tensioned catenary system comprise up to one mile long tension sections which overlap with adjacent tension sections at each end. Each tension section has balance weights at each end, and the midpoint is anchored against along-track movement. Actual tension lengths are designed taking into consideration the mechanical constraints of the system, such as displacement of contact wire due to

[2] **AREMA Manual for Railway Engineering**, Chapter 33, Electrical Energy Utilization, Part 4, published in 1991

swinging cantilevers, tension loss along the system, balance weight travel, and conductor length manufacturing limits.

The Metra upgraded catenary system will not be a typical modern new auto-tensioned system, because of the need to utilize the existing structures. Since the structures are spaced at relatively long spans, the upgraded conductors will have higher than normal conductor tensions. The Metra spans, being approximately 300 feet long are approximately 25% longer than used in a typical new AC electrification systems built elsewhere in the world.

The Metro North Commuter Railroad (MNCRR) lines north of New York are recent example of conversion of old fixed-termination catenary system to modern auto-tensioned catenary system using existing structures and new catenary system conductors and support brackets. Similar to Metra, the structures are constructed at 300 feet spacings. The MNCRR lines were rebuilt one track at a time while electric trains ran on the other three tracks. At the same time, the contact wires were lowered several feet, allowing the messenger wires to pass under the existing portal structures. At low bridges a new design of resilient support was developed. The catenary system was designed for train speeds up to 110 mph. Train consists include a variety of both locomotive-hauled trains as well as electric multiple units.

5.6 CATENARY SYSTEM CLEARANCES

5.6.1 Available Structural Openings

The issue of clearances becomes very important when considering electrification systems at 12.5 kV AC and 25 kV AC. Reconstruction of low bridges and track lowering, in order to provide adequate headroom for the catenary system, can represent a significant cost element in an electrification project. This expenditure could, in certain circumstances, sway against selection of the higher electrification voltage.

The available clearances under existing bridges and the suitability of bridges for high voltage electrification system were investigated in the following steps:

- Metra staff identified low clearance bridges that may encroach into the electrification system envelope and measured clearances form the top of rail to the bottom of the bridge.
- Considering track tolerances, rolling stock dimensions, dynamic characteristics, minimum pantograph operating height, catenary installation tolerances, and electrical clearances, the minimum acceptable rail-to-overhead structure clearances were developed for the 12.5 kV AC and 25 kV AC electrification voltages.
- A brief economical evaluation was made for critical obstructions to determine the cost of lowering the track.
- An initial cost estimate was prepared for each location along the Metra system where a significant civil reconstruction will be needed. The cost of track lowering was included in the cost estimate.

The overhead clearances available at lowest bridges along the Metra Electric District are listed in Table 5-3.

Table 5-3 - Overhead Structure Clearances

Bridge Location	Measurement	Top of Rail to Bottom of Bridge Clearance (feet, inches)			
		Track 1	Track 2	Track 3	Track 4
Chicago Eastern Illinois (CEI) Bridge at 120th and Front Street	South End	17' 8.5"	18' 0"	-	-
	North End	17' 8.5"	18' 0"	-	-
95th Street	South End	17' 9.5"	17' 11.5"	17' 9.5"	17' 9.5"
	North End	18' 0"	18' 0"	18' 3"	18' 3.5"
79th Street	South End	17' 3.5"	17' 5"	17' 0"	17' 2.5"
	North End	17' 2"	17' 1"	17' 1"	17' 2"
76th Street	South End	18' 3"	18' 5.5"	17' 9.5"	17' 9"
	North End	18' 3.5"	18' 2.5"	18' 0"	17' 7.5"
35th Street	South End	17' 7"	17' 3"	17' 6"	17' 9"
	North End	17' 8.5"	17' 3.5"	17' 6.5'	17' 8.5"
31st Street	South End	19' 10"	19' 1.5"	19' 4.5"	19' 4.5"
	North End	19' 0"	18' 4"	18' 8"	18' 11"

5.6.2 Minimum Clearance Required

The minimum required clearances for 12.5 kV AC and 25 kV AC electrification systems are developed in Table 5-4.

Table 5-4 - Minimum Vertical Opening for Catenary System at Support Location

Parameter	12.5 kV AC System		25 kV AC System	
	(feet)	(inches)	(feet)	(inches)
Track Maintenance Vertical Tolerance		2		2
Minimum Pantograph Operating Height	16	4	16	4
Contact Wire Erection Tolerance		1		1
System Height[3]		1		1
Wire Uplift Due to Low Temperature[4]		0		0
Wire Uplift Due to Pantograph Pressure		1		1
Electrical Clearance from Wire to Underside of Bridge		5		8
Distribution System Vertical Opening	**17**	**2**	**17**	**5**

[3] Double contact wire system is assumed. System height is equal to the wire diameter.

[4] Auto-tensioned catenary system is assumed.

The normal minimum electrical clearances of 5 inches and 8 inches for 12.5 kV AC and 25 kV AC electrification systems, respectively, used in Table 5-4, are so-called normal passing clearances which exist only during passage of the rolling stock, as defined by the American Railway Engineering and Maintenance-of-Way Association (AREMA)[5].

Using the absolute minimum passing clearances of 3 inches and 5 inches would result in the Distribution System Vertical Opening of 17 feet 0 inches for the 12.5 kV AC system and 17 feet 3 inches for the 25 kV AC systems. On the basis of data in Tables 5-3 and 5-4, the available clearance above the Distribution System Vertical Opening is shown in Table 5-5.

Table 5-5 - Overhead Structure Clearances

Bridge Location	Measurement	Clearance (inches)		Remarks	Bridge Suitability	
		12.5 kV AC	25 kV AC		12.5 kV AC	25 kV AC
CEI	South End	6.5	3.5	Concrete slab deck supported on steel piers.	Yes	Yes
	North End	6.5	3.5		Yes	Yes
95th Street	South End	7.5	4.5	Concrete deck supported on concrete encased steel beams and steel piers	Yes	Yes
	North End	10	7		Yes	Yes
79th Street	South End	-2	-5	Abandoned steel bridge. Clearances are too low for electrification at either voltage. Raise or remove the bridge.	**No**	**No**
	North End	-1	-4		**No**	**No**
76th Street	South End	7.5	4.5	Steel bridge. Space for wire attachments exists.	Yes	Yes
	North End	5.5	2.5		Yes	Yes
35th Street	South End	1	-2	Concrete deck supported on steel beams and concrete piers. Clearances are too low for electrification at 25 kV AC voltage.	Yes	**No**
	North End	1.5	-1.5		Yes	**No**
31st Street	South End	23.5	20.5	Concrete deck supported on steel beams and concrete piers.	Yes	Yes
	North End	14	11		Yes	Yes

5.7 UPGRADE IMPLEMENTATION PLANNING

In order to upgrade the Metra catenary system, it will be necessary to prepare bid documents, including technical specifications, drawings and staging plans. These documents will form an integral part with the work of other disciplines and be part of a master plan.

5.7.1 Specifications

Based upon design criteria which will have to be developed first, and depending on the selected power supply system type, the catenary system will be specified to comprise messenger wire, auxiliary messenger (if required), and contact wire. The major characteristics of the system,

[5] **AREMA Manual for Railway Engineering**, Chapter 33, Part 2.

conductor sizes and material, conductor tensions and system height will be specified. Also, the conductor blow-off, mid-span offsets and wire stagger values will need to be determined. This analysis needs to be based on pantograph security calculations, taking into account the vehicle roll, pantograph sway, wire blow-off, and track maintenance tolerances. The existing catenary system structure spacings on tangent and curves will most likely determine the necessary conductor tensions required to satisfy the previously developed midspan-offset criteria.

5.7.2 Catenary Drawings

Based on this input data, catenary layouts should be developed to determine the locations of the catenary overlaps having due regard for the requirements of the sectionalizing plan. Based on overlap locations, structure locations will be selected for mounting the counterweight assemblies. Wire heights and staggers will be calculated. Special bridge arrangements will be prepared for low-clearance bridges. Support assemblies for carrying the new conductors will be designed, and materials lists prepared. Conductor schedules will be developed listing every tension length of conductor required to complete the work.

In order not to preclude a later increase in catenary voltage, consideration should be given to using insulators rated at the higher AC voltage, even if the short-term choice of voltage is to upgrade the 1,500 V DC system.

5.7.3 Staging Plans

Staging plans will be prepared where necessary single-track possession. Two-track possessions in the areas of track crossovers will need to be checked for compatibility with the service schedules. Changes to the catenary layouts may be required to facilitate construction on some tracks where track access is more difficult. Some work involving crossovers which will impact more than one track, will need to be completed during the nights or at week-ends, and must be sequenced withing the overall track possession program.

The contractor work will include preparation of final cross-sections for each of the existing structures, including developing the necessary support brackets and allocating the required catenary components. Attachment of the counterweight assemblies to the existing portal structure columns will necessitate additional hardware before actual catenary reconstruction can begin.

6. SIGNAL SYSTEM

6.1 SIGNAL SYSTEM CAPABILITY FOR 79 MPH OPERATION

6.1.1 Existing System Description

The existing Mainline signal system is designed to enable the trains to run at a maximum speed of 65 mph. The safe braking distance of the existing rolling stock for 65 mph operation is 3,000 feet. Since the new rolling stock data are not available at this time, a 4,500 foot braking distance from the future maximum speed of 79 mph is assumed. For train operation at 79 mph, the signal system would have to be modified in many locations.

The average existing block length is approximately 2,500 feet. Assuming that the shortest block length is about 2,000 feet and this block is followed by a block 2,500 feet long, the combined block length achieves the desired 4,500 foot braking distance needed for the new trains operating at 79 mph maximum speed. Using the existing system advance approach rule #9.1.6 (flashing yellow aspect), two signals blocks with the total distance of 4,500 feet can be considered as shown in Figure 6-1. In the same Figure the Train #1 has a clear signal. The following Train #2 has a flashing yellow aspect (advanced approach signal), directing the train operator to proceed, prepare to pass the next yellow signal not exceeding 40 mph, and prepare to stop at the second red signal, if the Train #1 still occupies the same block. Braking distance for 40 mph is approximately 1,800 feet which means that the Train #2 would have 200 feet before it would enter the block occupied by Train #1.

Figure 6-2 shows a signal layout without using the advanced approach rule. Since the block lengths are 4,500 feet, the trains are spaced at greater distances then was possible with the advanced approach rule. Therefore, the trains would have to be dispatched at longer headways, and the system passenger throughput capacity could be affected.

The existing signal system currently has directions of traffic as follows:

- From MP 1.54 to 67th Street
  - Tracks #1 and #2 - Automatic Block Signal (ABS) Southward
  - Tracks #3 and #4 - Automatic Block Signal (ABS) Northward

- From 67th Street to Kensington Interlocking
  - Track #1 - Controlled Block Signals (CBS) Both Directions
  - Track #2 - Automatic Block Signal (ABS) Southward
  - Track #3 and #4 - Automatic Block Signal (ABS) Northward

- From Kensington to University Park
  - Track #1 and #2 - Centralized Traffic Control (CTC) bi-directional

6.1.2 Existing System Upgrade

6.1.2.1 Main Line Track #1 from Roosevelt Road to 67th Street

There are only four signal blocks that meet the 79 mph braking distance requirements, and therefore, signal re-spacing will be needed. From 67th Street to Kensington, the shortest block length is 2,315 feet and since the block length on both sides exceeds 2,200 feet, satisfactory braking distances would be obtained with the advanced approach signal rule.

In Figure 6-3, the Train #1 is on a C-track (CT) which has a block length of 2,315 feet. The Train #2, just beyond E-track (ET) receives a flashing yellow aspect.

In Figure 6-4, the Train #1 is on a B-track (BT) and the Train #2 still has 5,060 feet of braking distance. In the event that the D-track (DT) has a block length less than 2,185 feet, it would be necessary to re-space that block.

6.1.2.2 Main Line Track #2 from Roosevelt Road to 67th Street

There are only four signal block lengths that meet the 79 mph braking distance requirements, and therefore, signal re-spacing will be needed. From 67th Street to Kensington, all signal block lengths meet the future maximum speed requirements.

6.1.2.3 Main Line Track #3 and Track #4 from Roosevelt Road to Kensington

No re-spacing is needed to 51st Street. Re-spacing is needed between 51st Street and 67th Street interlockings. Since the distance between these interlockings is 7,413 feet, this distance should be broken up into three separate blocks.

6.1.2.4 Main Line Track #1 and Track #2 South of Kensington

South of Kensington the signal spacing is satisfactory to run trains at 79 mph using the advanced approach rule. However, system modifications will be required for this speed of operation.

6.2 SIGNAL SYSTEM COMPATIBILITY

6.2.1 Compatibility with New Propulsion System

At the time of writing this report, NICTD has equipped eight of its existing cars with Toshiba DC to AC inverter propulsion systems and successfully performed extensive field testing over various types of signal apparatus, including the following equipment that is also used by Metra:

- US&S SLV-13 Power Frequency Vane Track Relay
- US&S Model 15 Power Frequency Vane Track Relay
- Harmon Industries Electrified Electro Code (E^2 Code) 156 Hz Track Circuit
- Harmon Industries Epic II 1.0 kHz and 1.5 kHz Track Circuit

- Safetran PSO II 645 Hz and 1450 Hz

The tests demonstrated that the NICTD and Metra signal systems are compatible with the new inverter drives.

6.2.2 Compatibility with AC Electrification System

Majority of newer railroad signal installations in electrified territory have typically employed solid-state coded track circuits. These track circuits not only insure compatibility with the electrification system, but also transmit coded energy through the track for signal controls, thereby eliminating the need for cables between signal locations. Beginning in the mid-1990's, Metra embarked on a program to replace its aging track circuits technology on the Electric Division with this new solid state technology.

A preliminary review of the solid-state track circuits now being installed on the Metra Electric District indicates that the equipment is compatible for AC electrification systems operating at either 12.5 kV AC or 25 kV AC.

6.3 CURRENT METRA/NICTD PROJECTS AND STUDIES

Currently Metra has several re-spacing projects underway which will meet the new 79 mph maximum speed requirements between the new interlocking CP 1.34 and the new interlockings CP 65th, 67th, and 69th Streets. With completion of the signal re-spacing project from 69th Street to Kensington, the signal system will be capable of handling maximum train speed of 79 mph.

With this design, the 51st Street interlocking will be retired and a new interlocking, called CP 45th Street, will be installed. All new interlockings will be controlled from the Consolidated Control Facility (CCF). Also, the interlockings at Homewood, Richton Park, and University Park are now being controlled from the CCF.

Also, the Northern Indiana Commuter Transportation District (NICTD) has a ongoing study to improve their operations at the Kensington interlocking.

7. COMMUNICATIONS SYSTEM

7.1 GENERAL

The requirement for communications system equipment and cable runs, as well as modifications needed to the Central Control Facility (CCF) are evaluated for the three systems under consideration:

- Upgrade of the existing 1,500 V DC system. The system upgrade would include 4 new traction power substations, converting 3 tie stations to substations, and 5 new tie stations.
- New 12.5 kV AC system. The system would include two traction power substations, two paralleling stations, and one switching station.
- New 25 kV AC system. The system would include two traction power substations, two paralleling stations, and one switching station.

7.2 COMMUNICATION PROVISIONS FOR NEW FACILITIES

A Supervisory Control and Data Acquisition (SCADA) System for monitoring and controlling the traction power system facilities and monitoring of fire alarm and doorway intrusion is currently installed and operational on the METRA Electric District. It is expected that any new system facilities, augmenting or replacing the existing systems, will be built with the same design criteria and will include similar provisions.

The SCADA system is connected to the CCF via two telephone data circuits, SCADA Main and SCADA Backup. One of the data circuits is the leased Ameritech data line and the second circuit is a data circuit channel in the existing Electric District fiber optic transmission system with Microwave Link back to CCF. The existing Metra fiber optic OC-3 transmission system and the telephone system are already sized to accommodate system expansion.

7.2.1 Upgrade of the Existing 1,500 V DC System

7.2.1.1 Substation Equipment

It is assumed that the new packaged substations and tie stations will include SCADA equipment comparable and compatible with the existing SCADA system. Each new facility will require the following communications system equipment:

- SCADA cabinet assemblies with RTUs for the substations and tie stations.
- CCTV system installed for local security purposes consisting of a camera located at each outside entrance wall for viewing the substation and tie station street doorway entrance and a CCTV monitor located just inside each entrance.

- Telephone instrument connected to METRA via a telephone DS-O channel in the fiber optic OC-3 transmission system or a leased telephone line from Ameritech.
- Fire Alarm Panel monitored remotely at the Randolph Street Control Room via a leased Ameritech telephone lines and provisions for monitoring at CCF via SCADA System
- Door intrusion circuits installed at each entrance with provisions for remote monitoring at CCF.
- Cable junction boxes with 25 pair telephone cables from the Metra ROW. Fiber optic transmission system will be required to the outside wall of the new facilities. These telephone cables will be terminated within the substations and tie stations for the eventual SCADA system data circuit and substation telephone line.
- Equipment and cabling to integrate the substation and tie station equipment to the existing METRA cable transmission system.

7.2.1.2 CCF SCADA Equipment and System Upgrade

Following is a list of items required to upgrade the Electric District Traction Power SCADA system network at the CCF:

- Additional SCADA equipment for the new substations and tie stations.
- New leased circuits from Ameritech for SCADA Backup telephone service.
- New circuit connections from the fiber optic equipment to the SCADA equipment.
- Connection of remote monitoring circuits for substation and tie station building fire alarm system and intrusion alarm indications.
- Reprogramming of the existing CCF SCADA system equipment to include monitoring and control of the new substations and tie stations, including software and graphic display upgrades.
- Redesigning and rebuilding existing SCADA Route Map Board to accommodate the new substations and tie stations.

7.2.2 New 12.5 kV AC or 25 kV AC System

7.2.2.1 Substation Equipment

In the event that the existing 1,500 V DC system is converted to a new 12.5 kV AC or 25 kV AC system, the two new substations, the two new paralleling stations, and the one new switching station will require the following communication system equipment:

- SCADA cabinet assemblies with RTUs for the substations, paralleling stations, and switching stations.
- CCTV system installed for local security purposes consisting of a camera located at each outside entrance wall for viewing the substation, paralleling station, and switching station street doorway entrance and a CCTV monitor located just inside each entrance.
- Telephone instrument connected to METRA via a telephone DS-O channel in the fiber optic OC-3 transmission system or a leased telephone line from Ameritech.
- Fire Alarm Panel monitored remotely at the Randolph Street Control Room via a leased Ameritech telephone lines and provisions for monitoring at CCF via SCADA System
- Door intrusion circuits installed at each entrance with provisions for remote monitoring at CCF.

- Cable junction boxes with 25 pair telephone cables from the Metra ROW. Fiber optic transmission system will be required to the outside wall of the new facilities. These telephone cables will be terminated within the substations, paralleling stations, and switching stations for the eventual SCADA system data circuit and substation telephone line.
- Equipment and cabling to integrate the substation, paralleling station, and switching station equipment to the existing METRA cable transmission system.

7.2.2.2 CCF SCADA Equipment and System Upgrade

Following is a list of items required to upgrade the Electric District Traction Power SCADA System Network at the main CCF:

- Additional SCADA equipment for the new substations, paralleling stations, and switching stations.
- New leased circuits from Ameritech for SCADA Backup telephone service.
- New circuit connections from the fiber optic equipment to the SCADA equipment.
- Connection of remote monitoring circuits for the new substations, paralleling stations, and switching stations building fire alarm system and intrusion alarm indications.
- Reprogramming of the existing CCF SCADA system equipment to include monitoring and control of the new substations, paralleling stations, and switching stations, including software and graphic display upgrades.
- Redesigning and rebuilding existing SCADA Route Map Board to accommodate the new substations, paralleling stations, and switching stations.

8. STORAGE AND MAINTENANCE FACILITIES

8.1 OBJECTIVE

As already discussed, the new Electric District fleet size for year 2020 is projected to include 185 cars, an increase of 20 cars over the current fleet size. The 20 additional cars would be divided into train consists as follows:

- Two additional 8-car trains will be added to the morning and evening rush hours.
- Two existing 6-car trains will be increased in size to 8-car trains during the morning and evening rush hours.

It is assumed that the practice of storing the train consists at night in the yards on the southern end of the district will be continued.

The objective of this section is to determine if existing storage yards have sufficient capacity to handle the 185 new cars, or cars plus locomotives. In the event that adequate facility is not available, it is required to determine what are the additional requirements. Mid-day storage between the morning and evening rush hours will be at 18th Street Yard or its future replacement.

The three options for the fleet under considerations, i.e., the EMUs, electric locomotives with coaches, and dual-power locomotive with coaches, have different storage and servicing requirements. The spatial requirements for overnight storage of the increased fleet size, with and without locomotives, and the extra needs of the dual-power locomotives to be fueled every day will be addressed.

8.2 POTENTIAL FOR STORAGE GROWTH

To satisfy the overnight storage requirements, the storage capacity of the yards on the electric district was verified. The sites were visited and the length of each storage track was measured. The usable length of each track was recorded and compared against the existing drawings of the storage yards.

The layup sheet provided by Metra served as a baseline and is shown in the Volume 1 of the study, Appendix I. Each track used for overnight storage was evaluated for its potential to store additional cars over the number of cars currently being stored.

Since train size is limited to eight cars due to the platform lengths on the territory, most storage tracks need to have at least 680 feet of usable length (8 x 85'car length). Shorter consists can be paired up to maximize the utilization of the storage tracks.

8.2.1 Blue Island Storage Yard

During 2000, the storage track called the Lumber Lead was electrified. This electrification added storage and made moving cars into the Rock Island District more efficient. However, the track is not long enough to store the additional 8-car trains proposed in the fleet size increase. Further, the service increase planned for the University Park zone would make equipment moves back north to Blue Island inefficient and would increase operating costs. During 2001, new crew quarters and station renovation will be constructed. The photograph at left shows the construction progress and the new catenary system being erected over the Lumber Lead track.

8.2.2 Matteson/Richton Storage Yard

Matteson/Richton yard is at full capacity and no additional cars can be stored there. Consists are routinely stored utilizing the full length of a track and extending over the switch at one end. The practice maximizes the utilization of the yard, but limits the flexibility of equipment moves. For example, if a mechanical failure incapacitates one train consist, other consists that could be substituted for the failed equipment could be blocked by the fouled switch. There is no additional land on the site on which another storage track could be built. Immediately west of track 5, there is a sharp drop off, and crew and mechanical offices building. Adding a track to the west would require a full-length retaining wall. For the purposes of this study that option was deemed to be impractical and was not considered further.

8.2.3 KYD Storage Yard

KYD, while the newest yard on the Electric District, doesn't have additional room for adding storage tracks. With the mainline on the east, the property is long and narrow, and the full width of it is taken up by the existing trackage, buildings, and parking lot.

It is possible that some of the existing trackage on the property could be used for overnight storage if other storage tracks are taken out of service during construction or renovations. That option would be of

limited value since most of the tracks lead into the building and are too short for most of the revenue trains.

8.2.4 University Park Storage Yard

Located at the furthest point south on the Electric District, the University Park appears to be the only location with sufficient land to accommodate additional trackage for storing the larger fleet. After measuring the usable length of each storage track, available storage space was analyzed. The only available space for an additional track is immediately west of the north storage track. Two six-car trains and one four-car train are usually laid-up there for overnight storage. The new track would provide about 1,380 feet of additional storage, and the two new eight-car trains could be stored there.

View looking south – area for new track is over the ditch at the right.

Further south along this track, Metra forces installed an 18 inch diameter concrete culvert. Drainage issues will need to be addressed when building the new track.

8.3 STORAGE REQUIREMENTS FOR FLEET ALTERNATIVES

8.3.1 EMU Fleet

After analyzing the available storage, and planning the use of the new track at the University Park storage yard, places were found for all 185 new cars to layup overnight. Figure 8-1 shows the storage plan at the University Park utilizing a new north track for the new trains and the existing tracks for the longer trains which increased from 6-cars to 8-cars. The first set of parentheses indicates the existing number of cars stored, the second set of parentheses indicates the number of cars stored in 2020.

8.3.2 Electric Locomotives with Push-Pull Bi-Level Cars

The 42 locomotives required to operate push-pull service significantly increases the storage requirements. Again, the available capacity at the three storage yards discussed above were analyzed for their capacity to meet the required storage requirement. It was found that some tracks are just long enough for eight-car trains, and when a locomotive is added, the total consist will be too long for that track. Minor re-organization of the storage pattern was done, and a count was made of the trains that would not fit into the existing yards. Three eight-car trains, one seven-car train, and one two-car train would not fit into the current yards. A concept for a new storage yard was developed around these requirements. In developing the concept, and the implementation costs for a new yard, the following assumptions were made:

- Property would be adjacent to the mainline.
- Property would be flat, and not require major grading, or environmental cleanup.
- Geometry of the yard would be governed by use of number 8 turnouts.

Figure 8-2 shows the concept of a new storage yard located near the southern end of the Electric District.

8.3.3 Dual Power Locomotives and Push-Pull Bi-Level Coaches

Similar to the electric locomotive train operation, the dual power locomotive-hauled trains would require a the new storage yard. Additionally, the locomotives would also require a refueling station. Figure 8-3 shows the concept of a new storage yard located near the southern end of the Electric District.

Using costs recently received by Metra for the design of the Clinton Street Fueling facility, and adjusting the land requirements to accommodate the fueling equipment with an extra track for the refueling operation, it is estimated in Appendix D that four million dollars is needed to implement the refueling service for the dual power locomotives.

9. LIGHT AND POWER TRANSMISSION LINE

9.1 FUTURE LOADS

The existing railroad light and power transmission line loads were determined in the Task 2. The investigation revealed that the circuits are relatively lightly loaded.

After reviewing the future signal circuit installation plans, new passenger stations loads, and maintenance facility details, it is apparent that the transmission system has an adequate spare capacity and can accommodate an increased level of loading in the future.

9.2 LINE AUGMENTATION

Due to the low line loadings and high spare capacity, increased loads along the system would cause a relatively minor impact on the overall Light and Power Transmission System. Therefore, no line augmentation beyond the current line rehabilitation program is recommended at this stage.

However, it should be noted that an in-depth analysis of transmission line voltage drops and the effects of adjacent substations supply failure have not been performed as a part of this review. When Metra is able to determine L&P power loadings more accurately via their upgraded SCADA System, a comprehensive analysis of the transmission system should be conducted.

9.3 OTHER CONSIDERATIONS

9.3.1 System Extension

The Mainline L&P system configuration south of the Vollmer Road BR. 28-86 & BR. 29-33 structures, which includes Matteson and University Park areas, relies wholly on local utility company power connections. This power distribution arrangement is completely isolated from the rest of the Mainline L&P transmission line system. It is suggested that consideration be given to L&P System extension and connections to the University Park Station area when implementing future L&P transmission line system rehabilitation program funding.

9.3.2 Line Simplification

Several areas of the system are served by several L&P Transmission Lines, but are relatively lightly loaded. In these instances it is recommended that Metra considers load relocations and simplification of the transmission line circuits.

10. REAL ESTATE REQUIREMENTS

10.1 LAND REQUIREMENTS

10.1.1 1,500 V DC System

The new package-type 1,500 V DC system substations and tie stations are of relatively small size. Size of the substations is typically 16 feet x 46 feet, while the size of tie stations is approximately 16 feet x 18 feet.

10.1.2 12.5 kV AC and 25 kV AC Systems

A typical substation will occupy an area of approximately 23,000 square feet of land, while a typical paralleling station and switching station will require approximately 3,500 to 4,500 square feet of real estate.

10.2 SITE VISITS

10.2.1 Identification of Locations of Major Facilities

Necessary site visits were made to identify possible locations for the major facilities required for electrification. These facilities will include traction power substations and the yard/maintenance and inspection facilities. Tie stations, paralleling stations, and switching stations are relatively small in comparison to substations and often can be located within the railroad right-of way. Substations, however require a larger area, usually well outside the railroad right-of way.

10.2.2 Site Evaluations

In locations of the traction power substations for 12.5 kV AC or 25 kV AC electrification system, particular attention was paid to locations of electrical power utility facilities. The preferred sites were those adjacent to utility system substations, close to locations where transmission lines are crossing the railroad, or where the lines run in parallel with the right-of-way. Such locations of substations minimizes capital cost and reduces regulatory delays associated with building of new high voltage transmission lines.

In general, the following activities were performed at each of the visited sites:

- Review of sites for physical features which would have an impact on its use, such as accessibility, terrain, streams, wetlands, and easements.

- Review of sites for apparent utility facilities and requirement for relocation.
- Review of sites for any indications that the site was used by a business or industry that may have dealt with contaminated or hazardous materials.

10.3 FUTURE ACTIVITIES

In the event that the 12.5 kV AC or 25 kV AC system is selected, any available reports and studies applicable to the sites should be reviewed and requirement for various types of permits should be identified.

The next step in this effort would be development of substation, paralleling station, and switching station equipment layouts to determine the size of the site required for each facility. An evaluation of available land along the right-of-way would also be required to establish to define facility access road and maintenance vehicle parking.

After potential sites have been identified, there is a need to assess each site. Typically, site process assessment will include cost of property appraisal, evaluation of adjacent land uses, local acquisition requirements, and utility connection requirements. Local governing agencies would also be contacted to fully coordinate utility, zoning, building, and landscape requirements.

11. ENVIRONMENTAL IMPACT

A brief investigation of the environmental impacts and benefits to be derived from the 1,500 V DC system upgrade and from the candidate electrification conversion systems of 12.5 kV AC and 25 kV AC was performed. General and specific evaluations pertaining to each alternative were carried out. This analysis addresses the impact of new wayside facilities and includes a review of electromagnetic field effects.

11.1 WAYSIDE FACILITIES

The 1,500 V DC substations and tie station can be often located on, or adjacent to the railroad right-of-way, and therefore cause a low environmental impact. In the case of the high voltage 12.5 kV AC and 25 kV AC electrification systems, the environmental issues should be considered more carefully due to the facility sizes.

A Phase I Environmental Site Assessment (ESA), per ASTM E1527-00, should be performed to determine the potential for the occurrence of any recognized environmental conditions on or near the property, such as the potential presence of any hazardous substances and petroleum products in structures, soil, groundwater, or surface water. The Phase I ESA would include site visits, review of site histories, review of regulatory agency records, and interviews with knowledgeable individuals. If necessary, a follow-up Phase II ESA could be conducted to determine the presence of soil or water contamination.

Existing soil conditions at the selected sites would also need to be evaluated. Possible resource of information include maps from the United States Department of Agriculture Soil Conservation Service and site soil borings. In the event that unstable soils are discovered, construction costs would increase.

Hydrologic impacts to the proposed sites would need to be determined by examining existing hydrologic conditions. If the hydrologic impacts identify any drainage problems, the construction costs would increase to provide for additional drainage.

Preliminary locations of wetlands should be identified with the help of National Wetland Inventory Maps. If wetlands are found and would need be filled, a permit might be required and project costs would increase to account for provision of substitute wetlands.

If Federal funding will be used to construct the project, the National Environmental Policy Act (NEPA) requirements must be considered. NEPA is federal government's basic national charter for protection of the environment. Issues considered in a NEPA study include potential impacts to endangered species, flood plains, wetlands, and various other environmental concerns.

Finally, activities necessary to identify and evaluate site accessibility, high voltage power line access, and potential impacts to adjacent properties need to be performed.

11.2 ELECTROMAGNETIC FIELDS

The subject of electromagnetic fields (EMF) have received controversial coverage in general as well as technical press. There is a general agreement that the EMF cause biological changes in human beings, but whether these changes are harmful or not is a subject of continuing research. Since 1956 the research concentrated on biological effects of EMF and their possible connection to health effects.
The most important issue lies in exposure assessment which is characterized by amplitude, direction, duration, and frequency of the EMF. The industry lacks a definition of dose and most studies recorded all parameters possible and attempt to correlate them with an observed biological effect.

A substantial number of federal government agencies sponsor EMF research including Department of Energy (DOE), Department of Health and Human Services (HHS), National Cancer Institute (NCI) and National Institute of Environmental health Sciences (NIEHS) with federal funding in millions of dollars. Also, private industry supports the research mainly through the Electric Power Research Institute (EPRI) which spent $16 million in each year 1992 and 1993.

Extensive literature reviews have been conducted by federal and state agencies (Florida, New York, California), and also by the World Health Organization and by the National Radiological Protection Board of the United Kingdom. This literature was reviewed to provide a concise evaluation of the state of progress to date. In general, all reviews have found the published literature inconclusive, yet most recommended that the health concerns should not be dismissed. Other relevant literature review includes guidelines established by organizations such as the World Health Organization (Environmental Health Criteria), International Non-Ionizing Radiation Committee (INIRC) of International Radiation Protection Association (IRPA) and the American Conference of Governmental Industrial Hygienists (ACGIH).

At present time, the United States has no national standards which establish acceptable limits of electromagnetic fields. However, electric field limits, such as those recommended by the National Electrical Safety Code (NESC), and the states of Florida, Oregon, New York and New Jersey should be reviewed during preliminary design of railroad electrification project.

Also, the major types of litigation and their effect on transmission line construction and siting of substations should be reviewed. The review should include the types of approvals needed from local zoning boards, city managers or city councils.

12. SYSTEM COST ESTIMATES

12.1 GENERAL

Preliminary cost estimates appropriate for this level of study were developed for each electrification system option. The options under consideration include:

- Augmentation of the existing 1,500 V DC system
- Conversion to a new 12.5 kV AC system
- Conversion to a new 25 kV AC system

In order to simplify the cost estimating effort, use of differential or "delta" pricing was used as much as possible. For example, when estimating maintenance costs of EMU and dual power locomotive-hauled trains, the maintenance costs of car body, operator's cab, doors, HVAC system, lighting, brakes, and trucks will be comparable for both types of trains and need not be carried in the evaluations. However, because of presence of diesel engine and alternator on the DPL, the additional maintenance cost of this equipment needs to be recognized.

All costs were estimated in year 2001 U.S. dollars and are presented in Appendices G, H, I, and J.

12.2 CAPITAL COST ESTIMATE

The capital cost estimates include the following:

- Rolling stock, new electric multiple-units operating at 1,500 V DC, 12.5 kV AC, and 25 kV AC.
- Traction power supply system, including costs of substations, ties stations, switching stations, and paralleling stations.
- Catenary system upgrade to auto-tensioned system and conversion to 12.5 kV AC and 25 kV AC system.
- Signal system modifications.
- Communications system additions.
- Expansion of storage and maintenance facilities.
- Diesel operation during conversion.

12.2.1 Traction Power Supply System

Construction cost estimates of traction power supply system facilities, *i.e.*, substations, tie station, paralleling stations, and switching stations were developed by adding costs of the individual items of equipment required for each installation. Overall traction power system cost estimates for the

three traction power system alternatives were derived as a sum of the costs for the required substations, paralleling stations, and switching stations.

Specific requirements dictated by the facility locations determined in the conceptual system design were taken into account, as well as the voltage level of the power utility supply connection, rating of the substation equipment, and variations in equipment type and quantities depending on the number of tracks supplied.

12.2.1.1 1,500 V DC System

Preliminary construction cost estimates of traction power supply system facilities, *i.e.*, substations and tie stations, were developed by adding costs of the individual items of equipment required for each installation. The costs of the substations for the 1,500 V DC traction power supply system augmentation includes the following:

- Utility System Interface - includes cost of AC disconnect switches, feeder cable, ductbank, and utility metering
- AC Switchgear - cost of AC circuit breakers and disconnect switches with their assemblies
- Rectifier Transformer - cost of traction power transformer of appropriate rating
- Rectifier - cost of rectified transformer of appropriate rating
- DC Switchgear - cost of DC circuit breakers with their assemblies
- DC Feeders - cost of DC feeder cables and ductbanks
- Grounding System - cost of ground mat
- Control System - cost of supervisory control and data acquisition system (SCADA) for monitoring and control of all functions in the facility.
- Auxiliary System - cost of AC and DC power systems
- Building - cost of prefabricated building and foundation

The costs of the tie stations for the 1,500 V DC traction power supply system augmentation includes the following:

- DC Switchgear - cost of DC circuit breakers with their assemblies
- DC Feeders - cost of DC feeder cables and ductbanks
- Grounding System - cost of ground mat
- Control System - cost of supervisory control and data acquisition system (SCADA) for monitoring and control of all functions in the facility.
- Auxiliary System - cost of AC and DC power systems
- Building - cost of prefabricated building and foundation

Costs estimates for the augmentation of the existing 1,500 V DC traction power supply system are shown in Appendix G. Back up cost data are developed in Appendix H.

12.2.1.2 12.5 kV AC and 25 kV AC System

Preliminary construction cost estimates of traction power supply system facilities, *i.e.*, substations, paralleling stations, and switching stations were developed by adding costs of the individual items of equipment required for each facility. The costs of substations for the two traction power supply systems include the following:

- Land Acquisition - costs of real estate needed for the substation equipment, and interface equipment with the high voltage utility equipment and overhead catenary system.
- General Work - cost of site clearing, site work, landscaping, grounding system, ductbanks, and cables.
- High Voltage System Interface at the Traction Power Substations - costs of line traps, disconnect switches, and circuit breakers.
- Transformers - cost of traction power transformers.
- Buildings - cost of general (structural, architectural, and civil), mechanical, and electrical provisions for control equipment and medium voltage switchgear.
- Medium Voltage Switchgear - cost of vacuum or SF_6 circuit breakers complete with operating mechanisms, control equipment, protective equipment, instrumentation, busbars and metal enclosures.
- Supervisory Control and Data Acquisition System (SCADA) - cost of SCADA system for monitoring and control of all functions in the facility.
- Overhead System and Track Interface - cost of termination structure, disconnect switches, and impedance bonds.

The costs of paralleling stations and switching stations for the two traction power supply systems include the following:

- Land Acquisition - costs of real estate needed the station equipment, and interface equipment with the overhead catenary system.
- General Work - cost of site work, grounding system, ductbanks, and cables.
- Autotransformers - cost of autotransformers.
- Building - cost of general (structural, architectural, and civil), mechanical, and electrical provisions for control equipment, and medium voltage switchgear.
- Medium Voltage Switchgear - cost of vacuum or SF_6 circuit breakers complete with operating mechanisms, control equipment, protective equipment, instrumentation, busbars and metal enclosures.
- Supervisory Control and Data Acquisition System (SCADA) - cost of SCADA system for monitoring and control of all functions in the facility.
- Overhead System and Track Interface - cost of termination structure and disconnect switches.

For the autotransformer system, there is an additional cost for the parallel feeders. To correctly price the autotransformer system option, costs are included for the feeder conductors and insulated supports. Possible incremental additional costs for the distribution system poles and foundations would be relatively low and are not included in this preliminary cost estimate.

Costs estimates for the implementation of new 12.5 kV AC and 25 kV AC traction power supply systems are shown in Appendix G. Back up cost data are developed in Appendices I and J, respectively.

12.2.2 Catenary System

The catenary conversion cost estimate is based on actual costs of performing very similar work on the Mertro-North project in New York state. The contractor direct costs for conversion from 12 kV AC fixed-termination system to 25 kV AC auto-tensioned system was $210,000 per single-track mile

(STM) in 1989. Assuming annual inflation of 4%, the original cost need to be escalated by 60%. Therefore, the 2001 cost is estimated to be $336,000 per single-track mile.

The conductors for the 1500 V DC are in place and need not be replaced. The conductors for 12.5 kV AC system and 25 kV AC system will be smaller and therefore lighter, but the conductor lengths form anchor to anchor are identical. This results in the same number of counterweight structures for each system. Similarly, the mechanical components, counterweight assemblies, pulley supports and registrations will be similar for all three systems under consideration. Taking into consideration the similarities and differences of the DC and AC electrification system, the cost of conversion of the existing fixed-termination catenary system to auto-tensioned catenary system is estimated to be $50,000 per single-track mile.

12.2.3 Signal System

Cost estimates of the existing signal system modifications required to run trains at the maximum speed of 79 mph and the cost of the system upgrade to ensure compatibility with the new propulsion system and AC electrification were prepared and are included in Appendix G. The costs include block signals and grade crossings.

12.2.4 Communications System

Costs estimates for the upgrade of the existing 1,500 V DC communications system and for implementation of the new 12.5 kV AC and 25 kV AC communications systems were prepared and are included in Appendix G. The costs include substation, tie station, paralleling station, and switching station equipment, CFF equipment, database reprogramming, and testing and commissioning.

12.2.5 Storage and Maintenance Facilities

Costs estimates for the storage and maintenance facilities for the existing 1,500 V DC traction power supply system and for storage and maintenance facilities for the new 12.5 kV AC and 25 kV AC systems were prepared and are included in Appendix G. The costs include expansion of Crew and Mechanical Office Building and tools and equipment.

12.2.6 Light and Power Transmission Lines

The Light and Power Transmission Lines will continue to be supplied by the existing DC traction power substations. In the event of electrification system change, the traction power supply equipment can be de-commissioned, but the Light and Power Transmission Lines can be supplied from the same utility feeders as at present. Therefore, since there is no cost impact due to the electrification system change, no cost estimates were prepared.

12.2.7 Real Estate

The required real estate is estimated at $10 per square foot and applied as required in Appendices D and G.

12.2.8 Diesel Operation

During the DC to AC system conversion, there will be requirement for diesel locomotive operation during certain times on various segment of the route. The costs are included in Appendix G and include leasing of diesel locomotives.

12.3 OPERATIONS AND MAINTENANCE COST ESTIMATE

An estimate of operating and maintenance costs was provided for each alternative presented in this study. The analysis includes the following:

- Operations Costs include the system point of supply charge, power demand charge, and energy consumption costs.
  - The point of supply charge is applied as a fixed charge at each substation.
  - The ENS software predicted kW power demand over the utility billing interval at each substation. The power demand was multiplied by the $/kW demand charge to determine the demand cost at each substation.
  - TPS software predicted the energy consumption in kWh/train trip consumed by the express trains operating between Randolph Street and Harvey, Flossmoore, and University Park, as well as the energy consumption for the local trains operating between Randolph Street and South Chicago and Randolph Street and Blue Island. Taking into account the number of trips per weekday, Saturday, and Sunday, the energy consumption in kWh/day was determined for each service. Finally, considering the number of weekdays, Saturdays, and Sundays per year, the annual energy consumption in kWh/year was derived. Applying the $/kWh cost to the annual energy consumption, the annual energy cost was calculated.
- Maintenance Costs Estimate. Maintenance costs were based on a typical yearly maintenance effort required for rolling stock, substations, overhead catenary system and other systems. Consideration was given to the number of personnel required, the personnel qualifications needed, and prevailing wages in the Chicago area.

12.4 LIFE CYCLE COST ESTIMATE

The life cycle cost estimates for each of the three systems options under considerations were calculated in Table 12-1 as a sum of the capital cost and the present worth of O&M costs.

The total capital cost was increased by so-called add-on amounts for contractor's mobilization and demobilization, consultant's design and engineering support, construction management, agency engineering support, agency construction support, compliance with specification's general conditions, environmental assessment effort, laboratory testing allowance, field testing and commissioning, spare parts, special tools and equipment, system documentation, training, and construction contingency.

The O&M costs were estimated over 30 year period using annual inflation rate of 4%. The present worth of the O&M costs was calculated assuming annual interest rate of 8%.

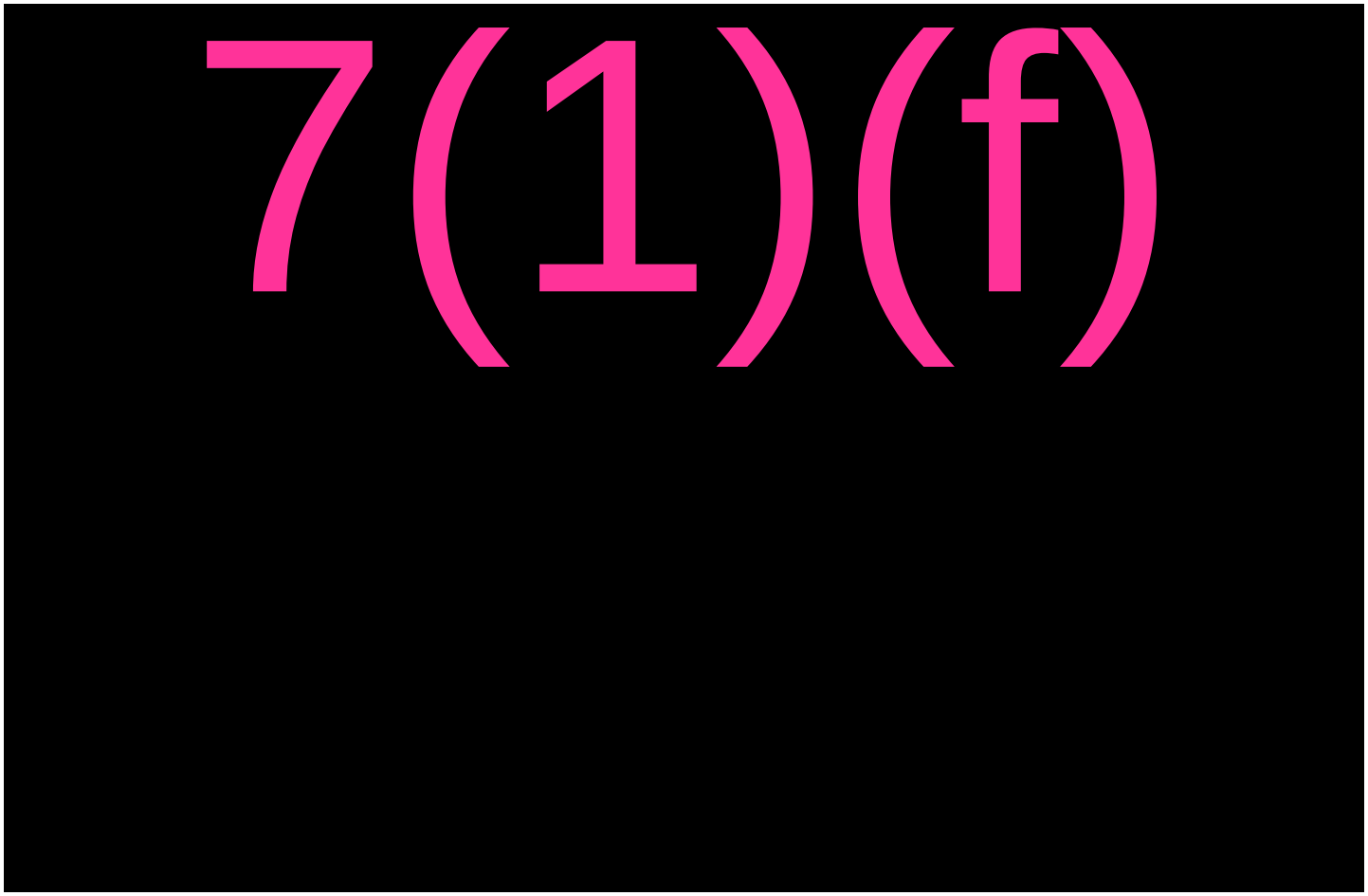
Table 12-1 -Traction Power System Life Cycle Cost Estimates

Traction Power System Option	Cost	Cost Estimate (millions of dollars)	Total Cost (millions of dollars)
Existing 1,500 V DC System Augmentation	Capital	745	823
	Operations and Maintenance	78	
New 12.5 kV AC System	Capital	857	931
	Operations and Maintenance	74	
New 25 kV AC System	Capital	914	987
	Operations and Maintenance	73	

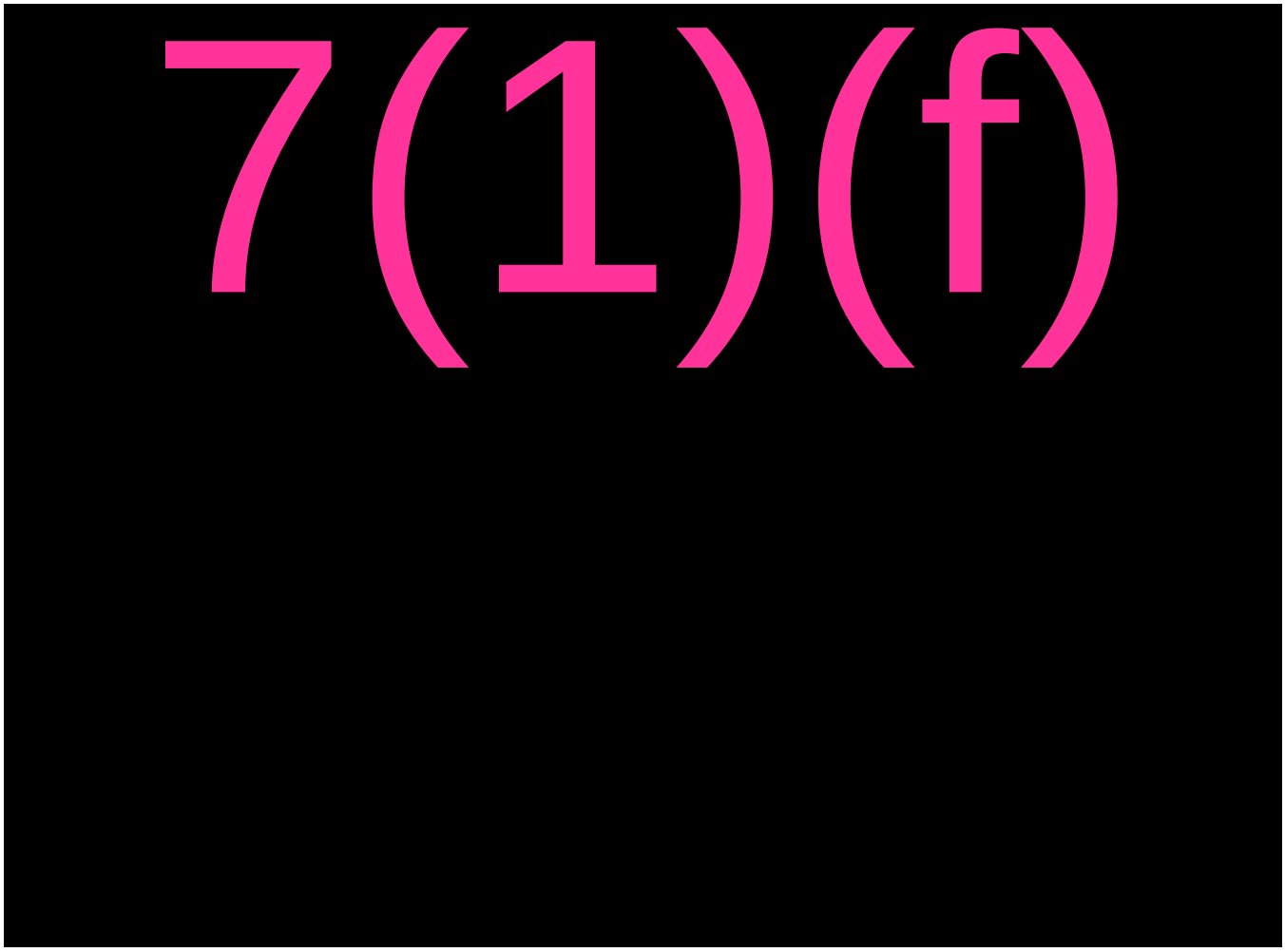
The table shows that the augmentation of the existing 1,500 V DC system is the most cost effective option overall. The system is in very good condition and its augmentation is recommended over the AC system alternatives due to the system cost advantage, higher flexibility, lower environmental impact, and minimum disruption to the traveling public.

13. CONCLUSIONS AND RECOMMENDATIONS

13.1 ROLLING STOCK



13.2 TRACTION POWER SUPPLY SYSTEM



13.3 CATENARY SYSTEM

13.4 SIGNAL SYSTEM

7(1)(f)

13.5 COMMUNICATIONS SYSTEM

7(1)(f)

13.6 STORAGE AND MAINTENANCE FACILITIES

7(1)(f)

13.7 LIGHT AND POWER TRANSMISSION LINE

7(1)(f)

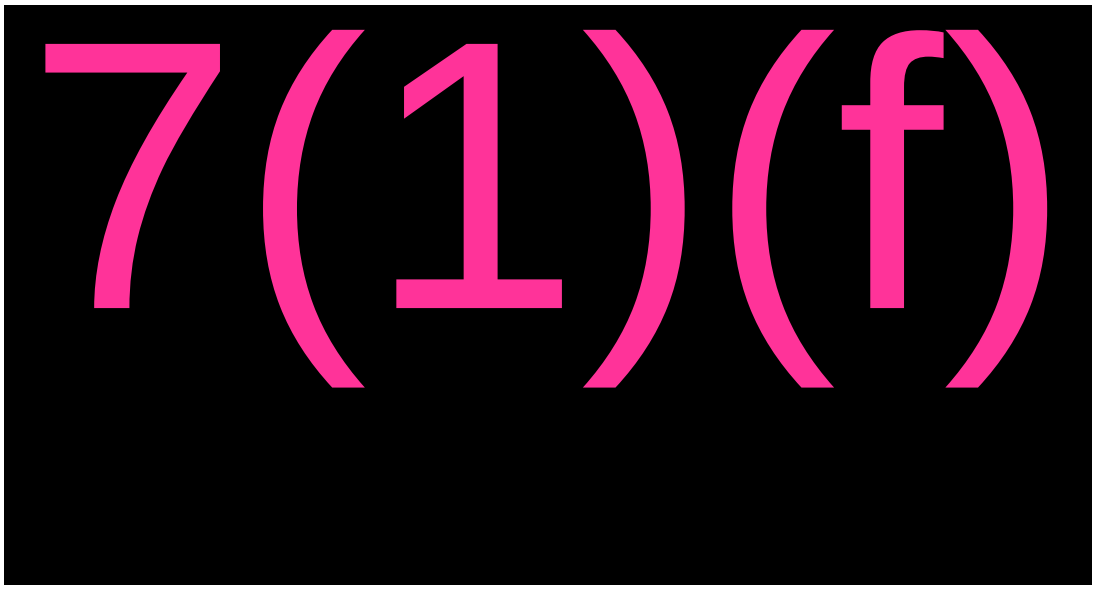
13.8 REAL ESTATE REQUIREMENTS

7(1)(f)

13.9 COST ESTIMATES

Preliminary cost estimates appropriate for this level of study were developed for each electrification system option. All costs were estimated in year 2001 U.S. dollars and are shown in Appendix G.

13.9.1 System Capital Cost



13.9.2 System Operations and Maintenance Cost

13.9.3 Cost Summary

Appendix A - GLOSSARY OF TERMS

A.1 GLOSSARY OF TERMS

Ampacity. Current-carrying capacity of a conductor, expressed in amperes.

Auxiliary Messenger Wire. Wire supported by the messenger which in turn supports the contact wire. The wire also acts as an auxiliary current conductor.

Catenary System. Overhead power distribution system providing traction power to electric locomotives and MU cars.

- Compound Catenary System - a system of messenger wire supporting an auxiliary messenger wire by the means of hangers which, in turn, support a contact wire by parallel groove clamps. The system is suitable for high speed application.
- Simple Catenary System - a system of messenger wire supporting a contact wire by the means of hangers. The system is suitable for medium speed to high-speed applications.

Catenary System Supporting Structures. Poles, towers, bridges, or other stationary structures used for supporting a catenary system including foundations, anchors, guys, braces, and similar reinforcing attachments.

Centralized Electrification Traffic Control (CETC) System. Computer-based system used for controlling operation of the traction power system and movements of trains.

Component. Item of complete hardware as commonly supplied by manufacturers.

Conceptual Design. A generalized plan describing design requirements and used as a guide to preliminary design.

Contact Wire. Conductor in contact with pantograph used by locomotives and MU cars to collect train power requirements. The conductor is suspended from messenger or auxiliary messenger by the means of hangers and contact wire clamps.

Contact Wire System. Overhead power distribution system providing traction power to electric locomotives and MU cars.

- Single Contact Wire System - a system of single contact wire without messenger or auxiliary messenger wire. The system is suitable for yard and shop applications.
- Twin Contact Wire System - a section of system where a contact wire is spliced into a messenger wire. The two contact wires are installed side by side and supported by insulated supports attached to the underside of a structure, such a overhead bridge. The system is used

in areas where the vertical clearance does not allow the use of compound or simple catenary systems. The system is suitable for medium speed to high-speed applications.

Directive Drawings. Drawings defining general arrangements or configurations of facilities for a particular project.

Disconnect Switch. A device used for disconnecting of de-energized items of equipment and sectioning of catenary system. Disconnect switches do not have a fault breaking capability, but may have some load breaking capability.

Distribution. Delivery of power from transmission system to an end-use customers at voltages greater than 110 V and less than 69 kV.

Electric Traction. A means for propulsion of railroad vehicles whereby power is provided by electrical energy transmitted from a remote source through a catenary system.

Final Design. A design stage during which final specifications, contract drawings, schedules, and cost estimates are prepared for specific construction project.

Frequency Converter. Frequency converter used for electrical traction purpose converts three-phase utility power of one frequency to single-phase power of different frequency.

- Rotary - Converter comprised of a three-phase motor and a single-phase generator.
- Static - Converter using semiconductor devices such as thyristors.

Grounded Equipment. Equipment connected to the conducting mass of the earth via ground rods, grounding grid or both to ensure an immediate discharge of electrical potential without danger.

Harmonics. Voltages and currents at frequencies other than the fundamental system frequency. Harmonics are caused by non-linear circuit components such as thyristors.

Harmonic Distortion. Due to the harmonic currents generated by thyristor-controlled equipment on board the rolling stock or in substations, the utility and traction voltage and current waveforms are not sinusoidal.

Impedance Bond. An iron-core coil of low resistance and relatively high reactance used to confine signaling current to its own track circuit and to provide a continuous path for the traction return current around insulated joints to substation.

Messenger Wire. Upper wire in a catenary system from which the contact wire is suspended by means of hangers.

Milepost. An identifier for a given location along a railroad line. Mileposts may or may not be located exactly one mile apart and may not be sequentially numbered.

Multiple-Fed System. Electrification system in which substations feed sections of catenary at multiple points. All conditions being equal, the multiple-fed system exhibits lower catenary voltage drop than the center-fed system. The system substations can have several traction power transformers or SFCs and operate with the substation low voltage bus-tie circuit breaker normally

closed. Multiple-fed systems do not usually operate at commercial frequency because the entire system must be supplied at the same phase.

Power Demand Analysis and Load-Flow Study. A computer-aided study using specially written computer program to calculate the combined performance of the traction power supply and traction power distribution systems with operating trains. The study results include catenary system voltages, catenary system currents, substation power demand requirements and substation energy consumption.

Power Factor. Ratio of useful (real) power to total (apparent) power. Power factor is dependent on the locomotive propulsion system and substation converter design. Generally, the power factor is low at low trains speeds and improves as the speed increases.

Power Transmission Factor. Ratio of transmitted power to power transmission capability.

Preliminary Design. A design stage at which specifications and drawings clearly show all major design elements and define requirements for final design. Design calculations are substantially complete, cost estimates are detailed to an extent compatible with the level of design, and a preliminary construction sequence schedule is prepared.

Span. Distance between catenary system structures.

- Length - Along track distance between structures.
- Width - Across track distance between the poles of a cross-span or headspan.

Station Dwell Time. That amount of time during which a train is stopped to open and close doors and receive and/or discharge passengers.

Substation. Traction power supply facility. Typical traction power substation includes power utility interface equipment, disconnect switches, circuit breakers, traction power transformers, switchgear, control equipment, signal power supply equipment, and auxiliary system. Special equipment, such as harmonic filtering and power factor control equipment, may be installed in substations as required. Substations serving electrification systems operating at other than commercial frequency also contain frequency converters.

Switching Station. Station containing circuit breakers or switchgear line up. Switching stations are located between substations and are used in AC electrification systems for switching section of distribution system during substation outage conditions and for paralleling of distribution system circuits.

Tie Station. Stations containing circuit breakers or switchgear line up. Tie stations are located between substations and are used in DC electrification systems for paralleling of distribution system circuits.

Traction Electrification System. Traction power supply and traction power distribution systems.

Traction Power Supply System. Traction power substations located at predetermined spacings along the route.

Traction Power Distribution System. Overhead catenary system or contact wire system which may be accompanied by overhead or underground along track feeders.

Trade-Off Analysis. A study of selecting a specific project alternative objectively considering all aspects related to all alternative methods of accomplishing the same action or an acceptable alternate action. Considerations include technical evaluations, environmental impact evaluations, and assessment of comparative costs.

Train Performance Simulator (TPS). A computer program representing operation of trains based upon tractive effort of the power units, resistance of the train to motion, and railroad alignment characteristics. TPS can calculate time, distance, speed, acceleration, power demand, energy consumption and loss relationships of a train for all station to station runs and for the whole route.

Transformer Cooling Class.

- OA - Self-Cooled
- FA - Forced-Air-Cooled
- FOA - Forced-Liquid-Cooled

Transmission. Delivery of power at a voltage of 69 kV or higher from generating units across interconnected high voltage facilities to points where the power enters distribution system.

A.2 LIST OF ABBREVIATIONS

A	Ampere
AAR	American Association of Railroads
A, B, C	High voltage system phase designations
AC	Alternating Current
ACSR	Aluminum Cable Steel Reinforced
APTA	American Public Transportation Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
AW0	Weight of empty, ready-to-run vehicle
AW1	Weight of vehicle with full seated load
AW2	Weight of vehicle with design load
AW3	Weight of vehicle with full load
AW4	Weight of vehicle with crush load
cmil	Circular mil
CN	Canadian National
DC	Direct Current
EIS	Environmental Impact Statement
EMI	Electromagnetic Interference or Electromagnetic Induction
EMM	Energy Management Model
ENS	Electric Network Simulator
EPR	Ethylene Propylene Rubber
ESI	Electrostatic Interference or Electrostatic Induction

FA	Forced-Air-Cooled
FOA	Forced-Liquid-Cooled
HV	High Voltage
Hz	Hertz
IGBT	Insulated Gate Bi-polar Transistor
ICRR	Illinois Central Railroad
kA	Kiloampere
kcmil	Kilo circular mil
kV	Kilovolt
kVA	Kilovolt-Ampere
kVAr	Kilovolt-Ampere Reactive
kW	Kilowatt
kWh	Kilowatt-Hour
LV	Low Voltage
MA	Motor-Alternator Set
M/G	Motor-Generator Set
MV	Medium Voltage
MVA	Megavolt-Ampere
MVAr	Megavolt Ampere Reactive
MW	Megawatt
MWh	Megawatt-Hour
N. C.	Normally Closed
N. O.	Normally Opened
non-RR	Non-railroad, not belonging to railroad
OA	Self-Cooled
O&M	Operation and Maintenance
p. u.	Per Unit
RMS	Root-Mean-Square
ROW	Right-of-Way
RR	Railroad
SCADA	Supervisory Control and Data Acquisition
TPS	Train Performance Simulator
V	Volt
XLPE	Cross-Linked Polyethylene

Appendix B - TPS INPUT DATA

The TPS input data are shown in the following Tables:

- Alignment Data - Shown in Volume 2, Appendix C.
  - Gradients
  - Speed Restrictions
  - Passenger Station Locations, Train Dwell Times, and Passenger Load Factors
- Train Data
  - Electrical Data, Table B-1
  - Mechanical Data, Table B-2
  - Performance Data, Table B-3
  - Propulsion and Braking System Data, Table B-4
    - Tractive Effort versus Speed Characteristic, New 1,500 V DC EMU, Figure B-1
    - Tractive Effort versus Speed Characteristic, New 12.5 kV AC or 25 kV AC EMU, Figure B-2
    - Tractive Effort versus Speed Characteristic ALP-46 Electric Locomotive, Figure B-3
    - Tractive Effort versus Speed Characteristic Genesis Series 2 Dual-Power Locomotive, Figure B-4
    - Propulsion and Regeneration Efficiency, New EMU, Figure B-5
    - Propulsion and Regeneration Efficiency, ALP-46, Figure B-6
  - Prototypical 25 kV AC EMU, Bi-Level Gallery Car, Weight Development, Table B-5

B.1 ALIGNMENT DATA

The route alignment data for the Mainline, the South Chicago Branch, and the Blue Island Branch are presented in Volume 2, Appendix C. The data include:

- Route gradients
- Civil speed restrictions
- Passenger station locations, train dwell times, and passenger load factors

B.2 TRAIN DATA

Table B-1 shows the electrical data for EMUs and locomotives under consideration.

Table B-1 - Electrical Data

Data and Units		EMUs	Locomotives
Pantograph Voltage	Nominal	1,500 V DC, 12.5 kV AC, or 25 kV AC	
	Maximum	1,600 V DC, 13.75 kV AC, or 27.5 kV AC	
	Minimum	1,050 V DC, 8.75 kV AC, or 17.5 kV AC	
Auxiliary Power, kW/Car		35	35

Table B-2 shows the mechanical data for the EMUs and locomotives under consideration.

Table B-2 - Mechanical Data

Data and Units		EMUs		Locomotive-Hauled Trains			
		1,500 V DC	12.5/25 kV AC	ALP-46	Genesis 2 DPL	Trailing Cars	Cab Cars
Length, ft		85	85	64	69	85	85
Frontal Area,ft^2		180	150	115	120	N/A	N/A
Train Consist Sizes		2, 4, 6, or 8	2, 4, 6, or 8	1	1	Up to 8	1
Flange Resistance Coefficient, estimated, lbs/ton/mph		.071	.071	0.045	0.030	0.030	0.030
Air Drag Resistance Coefficient	Locomotive or Front Car, lbs/ton/mph^2	0.0024	0.0024	0.0024	0.0024		
	Trailing Cars, lbs/ton/mph^2	0.00034	0.00034			0.00034	0.00034
Weight	Empty, tons	75.75	75.75	107.0	137.50	61.00	62.50
	Full Load, tons	88.00	88.00	107.0	137.50	77.80	76.90

Table B-3 shows the performance data for the EMUs and locomotives under consideration.

Table B-3 - Performance Data

Data and Units	EMUs		Locomotives	
	1,500 V DC	12.5/25 kV AC	ALP-46 Electric	Genesis 2 DPL
Speed, Maximum Operating, mph	100	110	100	110
Acceleration Rate, Maximum, mphps	2.0	2.0	1.5	1.0
Braking Rate, Maximum, mphps	2.0	2.0	2.0	2.0

Table B-4 shows the propulsion and braking system data for the EMUs and locomotives under consideration.

Table B-4 - Propulsion and Braking System Data

Data and Units		EMUs		Locomotives	
		1,500 V DC	12.5/25 kV AC	ALP-46 Electric	Genesis 2 DPL
Tractive Effort vs. Speed Characteristic		Figure B-1	Figure B-2	Figure B-3	Figure B-4
Propulsion and Regeneration System Efficiency		Figure B-5	Figure B-5	Figure B-6	-
Power Factor vs. Speed Characteristic		-	0.98 for all speeds	0.98 for all speeds	-
Fuel Consumption	Traction, gal/hr-hp	-	-	-	98.86
	Auxiliaries, gal/kW	-	-	-	263.64
	Idling, gal/hr	-	-	-	3.6
	Braking, gal/hr	-	-	-	9.0

B.3 VEHICLE CONVERSION to 12.5 kV AC or 25 kV AC

B.3.1 Prototypical 25 kV AC EMU, Bi-Level Gallery Car

Modern DC-supplied rolling stock uses the DC supply as an input to the variable voltage variable frequency (VVVF) inverter drives. AC-supplied rolling stock is required to carry an on-board transformer and rectifier in addition to the VVVF inverter drives. The variable voltage variable frequency output of the inverters feed AC induction motors. Induction motors have a very low maintenance requirements and, when supplied by the VVVF inverter drives, operate very efficiently.

This additional equipment associated with the AC power supply imposes a size, weight, and cost increment on the rolling stock. Since AC bi-level EMUs do not exist in this country, characteristics of prototypical EMU were developed.

The AC EMU weight was developed from the weight of the basic Chicago Metra bi-level, gallery car as shown in Table B-5.

Table B-5 - Prototypical 25 kV AC EMU, Bi-Level Gallery Car, Weight Development

Equipment	Basic Car Weight (lbs)	Weight Adjustments (lbs)	Total Weight (lbs)
Bi-Level, Gallery Car	140,000		
Cam Controller		-2,500	
Vacuum Circuit Breaker		300	
Transformer		5,000	
Reactors		2,500	
Controlled Rectifier		3,000	
IGBT Inverter		5,000	
Traction Motors		-1,400	
Brake Resistors		-400	
Total Adjustment		11,500	
		Total Weight	**151,500**

Assuming a propulsion system taking advantage of the latest technology, i.e., the insulated gate bi-polar transistor (IGBT) AC drive, a tractive effort curve was developed using Matlab (Simulink) based simulator, Table B-1, Appendix B. Acceleration of 2.0 mphps up to 20 mph speed was obtained while accounting for resistance to motion due to friction and wind effects. From approximately 35 mph to 70 mph, the tractive effort falls as $^{1}/_{speed}$, and above this speed, the tractive effort falls as $^{1}/_{speed}{}^{2}$, in accordance with the generic AC motor/inverter limitations. The curvature of the taper reflects optimized design of constant horsepower requirement for the traction drive in comparison to a straight line taper. Normal braking deceleration rate is assumed at 2.0 mphps.

Appendix C - TPS OUTPUT DATA

The TPS runs were performed for both outbound and inbound runs of each train type. The results presented in this Appendix include data for the express trains in southbound direction of travel.

- Express Trains, Harvey Zone
  - Existing EMUs, Table C-1.
  - New EMUs, Table C-2.
  - Electric Locomotive-Hauled Train, Table C-3.
  - Dual-Power Locomotive-Hauled Train, Table C-4.
- Express Trains, Flossmoore Zone
  - Existing EMUs, Table C-5.
  - New EMUs, Table C-6.
  - Electric Locomotive-Hauled Train, Table C-7.
  - Dual-Power Locomotive-Hauled Train, Table C-8.
- Express Trains, University Park Zone
  - Existing EMUs, Table C-9.
  - New EMUs, Table C-10.
  - Electric Locomotive-Hauled Train, Table C-11.
  - Dual-Power Locomotive-Hauled Train, Table C-12.

C.1 EXPRESS TRAINS, HARVEY ZONE

C.2 EXPRESS TRAINS, FLOSSMOORE ZONE

C.3 EXPRESS TRAINS, UNIVERSITY PARK ZONE

Appendix D - ROLLING STOCK COST ESTIMATE

D.1 ROLLING STOCK CAPITAL COST

The capital cost estimate associated with rolling stock replacement is presented on the following spreadsheets:

- Rolling Stock Cost Estimate, Table D-1
  - Electric Multiple Units
  - Electric Locomotive-Hauled Trains
  - Dual Power Locomotive-Hauled Trains
- Storage and Maintenance Facilities Cost Estimate, Table D-2
  - Electric Multiple Units
  - Electric Locomotive-Hauled Trains
  - Dual Power Locomotive-Hauled Trains

D.2 OPERATIONS AND MAINTENANCE COST

The rolling stock operations and maintenance cost estimate is presented on the following spreadsheets:

- Maintenance Cost Estimate, Table D-3
  - Electric Multiple Units
  - Electric Locomotive-Hauled Trains
  - Dual Power Locomotive-Hauled Trains
- Present Worth of Operations and Maintenance Cost Estimate, Table D-4
  - Electric Multiple Units
  - Electric Locomotive-Hauled Trains
  - Dual Power Locomotive-Hauled Trains

D.3 COST SUMMARY

- Cost Summary, Table D-5
  - Capital Cost Estimate
  - Operations and Maintenance Cost Estimate
  - Life Cycle Cost Estimate

Appendix E - ENS INPUT DATA

Data collected for the ENS computer runs are presented in the following Tables:

1,500 V DC System

- Per Unit Data, Table E-1
- Utility System Data, Table E-2
- Substation Data, Table E-3
- Traction Power Distribution and Return System Data, Table E-4
- Distribution System Impedances - Per Unit Values, Table E-5

12.5 kV AC System

- Per Unit Data, Table E-6
- Utility System Data, Table E-7
- Substation, Paralleling Station, and Switching Station Data, Table E-8
- Feeder to Catenary Impedance, Table E-9
- Catenary System Impedance, Table E-10
- Distribution System Impedances - Table E-11

25 kV AC System

- Per Unit Data, Table E-12
- Utility System Data, Table E-13
- Substation, Paralleling Station, and Switching Station Data, Table E-14
- Catenary System Impedance, Table E-15
- Distribution System Impedances - Table E-16

E.1 ELECTRICAL NETWORK DATA

E.1.1 Per Unit System

The ENS input data are represented in the program in the per-unit system. By expressing system constants and variables in per-unit, comparison of performance of equipment at different ratings is simplified. Per-unit values are defined by the ratio shown in Equation E-1:

$$\textit{Per Unit Value} = \textit{A Number/Base Number} \qquad \textbf{(E-1)}$$

For electrical variables, the following per-unit values are defined:

- Per-Unit Voltage = Voltage/Base Voltage
- Per-Unit Current = Current/Base Current
- Per-Unit Impedance = Impedance/Base Impedance
- Per-Unit Power = Power/Base Power

The voltage, current, impedance and power must be in the same units as their base values. Any convenient number can be selected as a base. By assigning a base value to any two variables, the bases for the remaining two are automatically fixed in accordance with expressions:

- Voltage = Impedance x Current
- Power = Voltage x Current

For convenience, the Base Voltage and the Base Power are selected and the Base Current = Base Power/Base Voltage and Base Impedance = Base Voltage/Base Current. The selection of the Base Voltage and the Base Power is quite arbitrary and has no relationship to the substation ratings.

In practice, it is often convenient to transfer directly from ohmic impedances to per-unit impedances using Equation E-2:

$$\textit{Per Unit Ohms} = (\textit{Ohms x Base kVA})/(\textit{Base kV}^2 \textit{ x } 1{,}000) \qquad \textbf{(E-2)}$$

E.1.2 System Impedances

The electrical utility system and the traction power supply, distribution, and return systems are represented by resistance and reactances which are determined from the system and conductor characteristics. The following tables present the resistance and reactance data in the per-unit system for augmentation of the existing 1,500 V DC power system, the new 12.5 kV AC system, and the new 25 kV AC system.

Appendix F - ENS OUTPUT DATA

Traction power simulations were performed for the following electrification systems:

- Existing 1,500 V DC System Augmentation
- New 12.5 kV AC System
- New 25 kV AC System

The new EMU trains are operating at the maximum speed of 79 mph.

F.1 EXISTING 1,500 V DC SYSTEM AUGMENTATION

F.1.1 Voltage Profiles

Voltage profile with expanded voltage scale is presented in Figure F-1. The lowest catenary system voltages are above the Normal Lower Voltage Limit shown in Volume 2 of the study, Table B-1, Appendix B. The augmented 1,500 V DC system can be expected to operate satisfactorily in 2020 taking into account the projected traffic density.

F.1.2 Load Currents

The maximum catenary system load currents are shown in Table F-1.

Table F-1 - Maximum Catenary System Currents

Substation Name	Direction of Current Flow	Maximum RMS Current (A)
Substation 1	Northbound	253
	Southbound	501
Substation 2	Northbound	864
	Southbound	580
Substation 3	Northbound	794
	Southbound	836
Substation 4	Northbound	429
	Southbound	328
Substation 5	Northbound	516
	Southbound	805
Substation 6	Northbound	334
	Southbound	413
Substation 7	Northbound	727
	Southbound	551
Substation 8	Northbound	384
	Southbound	943
Substation 9	Northbound	488
	Southbound	389
Substation 10	Northbound	413
	Southbound	401
Substation 11	Northbound	409
	Southbound	437
Substation 12	Northbound	519

Substation Name	Direction of Current Flow	Maximum RMS Current (A)
	Southbound	562
Substation 13	Northbound	460
	Southbound	409
Substation 14	Northbound	709
	Southbound	45
Substation 15	Northbound	90
	Southbound	568

The maximum catenary current is 943 A is well below the rated currents of the catenary system of 1,870 A and 1,700 A derived in Volume 2 of the study, Tables B-2 and B-3, Appendix B. Therefore, the existing catenary system is adequate for future operation.

F.1.3 Substation Power Demands

The average power demand for the system substations is shown in Table F-2. Based on these loading, the Calculated Rating in MVA was developed as shown in Equation F-1 below.

Table F-2 -Substation Power Demands and Ratings

Substation Name	Average Traction Power Demand (MVA)					Calculated Rating (MVA)
	2 Hour	15 Minute	5 Minute	1 Minute	15 Second	
Substation 1	1.2	2.3	2.6	4.0	10.2	2.3
Substation 2	2.0	3.8	4.4	6.7	11.0	2.5
Substation 3	0.9	1.8	2.0	3.2	3.8	0.9
Substation 4	1.8	3.7	4.2	5.8	8.6	1.9
Substation 5	1.8	3.1	4.2	7.4	9.6	2.1
Substation 6	0.7	1.3	1.8	2.9	3.5	0.8
Substation 7	0.8	1.6	2.3	4.8	5.7	1.3
Substation 8	0.7	1.4	1.9	3.9	4.9	1.1
Substation 9	0.8	1.5	2.0	3.9	6.0	1.3
Substation 10	0.1	0.2	0.3	0.7	0.9	0.2
Substation 11	1.1	2.1	2.4	3.8	4.3	1.0
Substation 12	1.0	2.1	2.4	3.5	4.3	1.0
Substation 13	1.0	1.8	2.3	4.1	4.7	1.0
Substation 14	0.8	1.4	1.9	2.9	4.3	1.0
Substation 15	0.6	1.1	1.7	3.0	4.3	1.0
Total System Demand	15.2					

Considering the substation power demands, the existing substations are rated adequately to support the future power demands. The rating of the new substations for the system augmentation is recommended to be 2 MVA.

F.2 NEW 12.5 kV AC SYSTEM

F.2.1 Voltage Profiles

Voltage profile with expanded voltage scale is presented in Figure F-2. The lowest catenary system voltages are above the Normal Lower Voltage Limit shown in Volume 2 of the study, Table B-1, Appendix B. The new 12.5 kV AC system can be expected to operate satisfactorily in 2020 taking into account the projected traffic density.

F.2.2 Load Currents

The maximum catenary system load currents are shown in Table F-3.

Table F-3 - Maximum Catenary System Currents

Substation Name	Direction of Current Flow	Maximum RMS Current (A)
Substation 1	Northbound	220
	Southbound	83
Substation 2	Northbound	169
	Southbound	147

The maximum catenary current is 220 A which is well below the rated current of the catenary system of 870 A derived in Table 5-1. Therefore, the proposed catenary system would be adequate for future operation.

The maximum feeder system load currents are shown in Table F-4.

Table F-4 - Maximum RMS Currents - Feeder System

Feeder Name	Current (A) on 12.5 kV Base	Current (A) on 25 kV Base
FD1	89	45
FD2	31	16
FD3	66	33
FD4	92	46

The maximum feeder current is 46 A which is well below the rated current of the feeder system of 870 A derived in Table 5-1. Therefore, the proposed feeder system would be adequate for future operation.

The maximum autotransformer load currents are shown in Table F-5.

Table F-5 - Maximum RMS Currents - Autotransformers

Measuring Point	Current (A) on 25 kV Base	Current (A) on 50 kV Base	Power (MVA)
AT1	355	178	9
AT2	124	62	3
AT3	132	66	3
AT4	183	92	5

Based on the currents in Table F-5, a uniform autotransformer rating of 10 MVA was selected.

F.2.3 Substation Power Demands

The average power demand for the system substations is shown in Table F-6. Based on these loading, the Calculated Rating in MVA was developed as shown in Equation F-2 below.

Table F-6 -Substation Power Demands and Calculated Ratings

Substation Name and Transformer Number		Average Traction Power Demand (MVA)					Calculated Rating (MVA)
		2 Hour	15 Minute	5 Minute	1 Minute	15 Second	
Substation 1	1	7.6	14.7	16.4	22.0	29.4	9.8
	2	2.3	4.4	5.9	9.7	15.6	5.2
Substation 2	1	3.2	6.9	8.6	14.5	23.4	7.8
	2	2.8	5.0	7.7	17.8	31.3	10.4
Total System Demand		15.8					

Ratings of the new substations for the 12. 5 kV system are recommended in Table 4-5.

F.3 NEW 25 kV AC SYSTEM

F.3.1 Voltage Profiles

Voltage profile with expanded voltage scale is presented in Figure F-3. The lowest catenary system voltages are above the Normal Lower Voltage Limit shown in Volume 2 of the study, Table B-1, Appendix B. The new 25 kV AC system can be expected to operate satisfactorily in 2020 taking into account the projected traffic density.

F.3.2 Load Currents

The maximum catenary system load currents are shown in Table F-7.

Table F-7 - Maximum Catenary System Currents

Substation Name	Direction of Current Flow	Maximum RMS Current (A)
Substation 1	Northbound	141
	Southbound	55
Substation 2	Northbound	123
	Southbound	109

The maximum catenary current is 123 A which is well below the rated current of the catenary system of 870 A derived in Table 5-2. Therefore, the proposed catenary system would be adequate for future operation.

F.3.3 Substation Power Demands

The average power demand for the system substations is shown in Table F-8. Based on these loading, the Calculated Rating in MVA was developed as shown in Equation F-2 below.

Table F-8 -Substation Power Demands and Calculated Ratings

Substation Name and Transformer Number		Average Traction Power Demand (MVA)					Calculated Rating (MVA)
		2 Hour	15 Minute	5 Minute	1 Minute	15 Second	
Substation 1	1	7.3	14.1	15.7	21.0	27.8	9.4
	2	2.2	4.3	5.8	9.5	15.0	5.0
Substation 2	1	3.1	6.7	8.3	13.9	21.9	7.3
	2	2.7	4.9	7.4	16.8	29.2	9.7
Total System Demand		15.3					

Ratings of the new substations for the 25 kV system are recommended in Table 4-6.

F.4 SUBSTATION RATING PROCEDURE

F.4.1 DC Substations

The procedure for determining the "Calculated Rating" of substations in Table F-2 is based on the substation power demands calculated in the traction power system study. The power demands, determined over the 2-hour interval corresponds to the substation continuous rating. Similarly, the power demands over the 5-minute, and 15-second intervals correspond to the substation overload ratings of 150%, 400%, and 450% continuous rating, respectively. As shown in the equation below, the "Calculated Rating" of a substation is the maximum value of the following values:

- Maximum traction power demand calculated at the substation over 2-hour period divided by 1.5 (150%) and the estimated yard and station load.

- Maximum traction power demand calculated at the substation over 5-minute period divided by 3.0 (300%) and the estimated yard and station load.
- Maximum traction power demand calculated at the substation over 15-second period divided by 4.5 (450%) and the estimated yard and station load.

$$CR = MAX\left[\frac{S_{2hr}}{1.5} + S_{ys}, \frac{S_{5m}}{3} + S_{ys}, \frac{S_{15s}}{4.5} + S_{ys}\right] \quad \text{(F-1)}$$

where:

CR	is	Calculated rating of substation.
MAX	is	Designation for a maximum value of the terms in the brackets.
S_{2h}	is	Average value of maximum traction power demand calculated at the substation over 2-hour period.
S_{5m}	is	Average value of maximum traction power demand calculated at the substation over 5-minute period.
S_{15s}	is	Average value of maximum traction power demand calculated at the substation over 15-second period.
S_{ys}	is	Estimated demand due to yard and station load during rush hour.

F.4.2 AC Substations

The procedure for determining the "Calculated Rating" of substations in Tables F-4 and F-6 is based on the substation power demands calculated in the traction power system study. The power demands, determined over the 2-hour interval corresponds to the substation continuous rating. Similarly, the power demands over the 15-minute, 5-minute, 1-minute, and 15-second intervals correspond to the substation overload ratings of 150%, 200%, 250%, and 300% continuous rating, respectively. As shown in the equation below, the "Calculated Rating" of a substation is the maximum value of the following values:

- Maximum traction power demand calculated at the substation over 2-hour period and the estimated yard and station load.
- Maximum traction power demand calculated at the substation over 15-minute period divided by 1.5 (150%) and the estimated yard and station load.
- Maximum traction power demand calculated at the substation over 5-minute period divided by 2.0 (200%) and the estimated yard and station load.
- Maximum traction power demand calculated at the substation over 1-minute period divided by 2.5 (250%) and the estimated yard and station load.
- Maximum traction power demand calculated at the substation over 15-second period divided by 3.0 (300%) and the estimated yard and station load.

$$CR = MAX\left[S_{2hr} + S_{ys}, \frac{S_{15m}}{1.5} + S_{ys}, \frac{S_{5m}}{2} + S_{ys}, \frac{S_{1m}}{2.5} + S_{ys}, \frac{S_{15s}}{3} + S_{ys}\right] \quad \text{(F-2)}$$

where:

CR	is	Calculated rating of substation.
MAX	is	Designation for a maximum value of the terms in the brackets.
S_{2h}	is	Average value of maximum traction power demand calculated at the substation over 2-hour period.
S_{15m}	is	Average value of maximum traction power demand calculated at the substation over 15-minute period.
S_{5m}	is	Average value of maximum traction power demand calculated at the substation over 5-minute period.
S_{1m}	is	Average value of maximum traction power demand calculated at the substation over 1-minute period.
S_{15s}	is	Average value of maximum traction power demand calculated at the substation over 15-second period.
S_{ys}	is	Estimated demand due to yard and station load during rush hour.

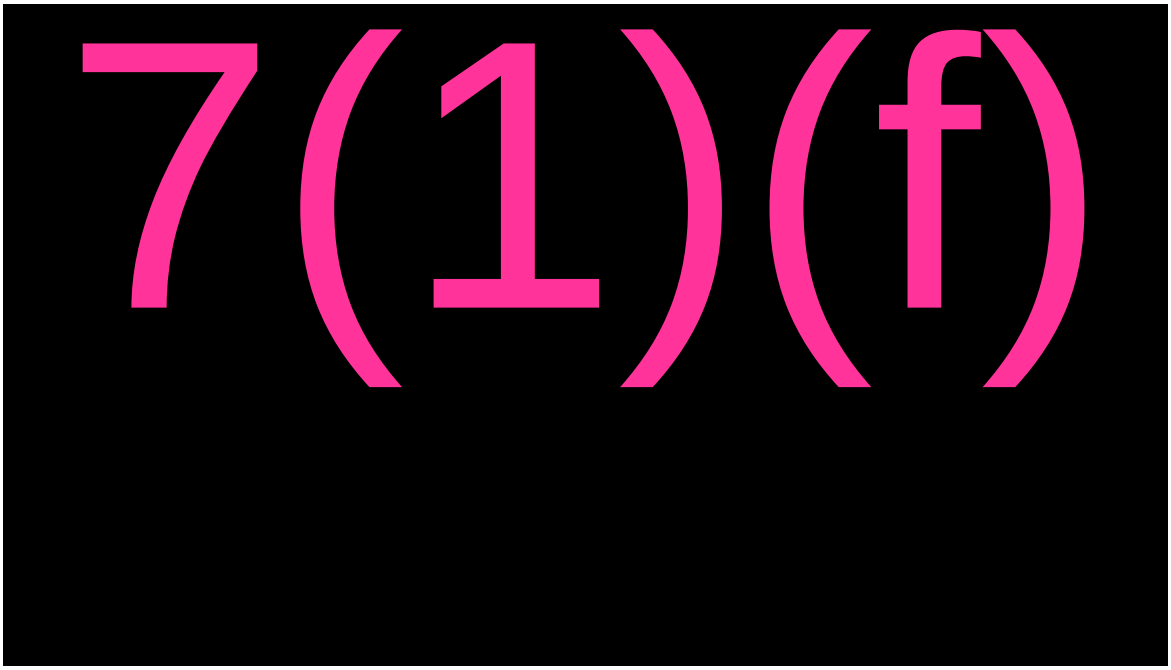
Appendix G - SYSTEM COST ESTIMATES

In order to compare the three systems under consideration, the following cost estimates were developed for the existing 1,500 V DC system augmentation, the new 12.5 kV AC and 25 kV AC systems.

G.1 SYSTEM CAPITAL COST

G.2 SYSTEM OPERATIONS AND MAINTENANCE COST

The system operations and maintenance cost estimate is presented in the following tables:



G.3 COST SUMMARY

Appendix H - EXISTING 1,500 V DC SYSTEM COST AUGMENTATION BACKUP

The backup for the Metra Electric District augmentation cost estimate is presented on the following tables:

Installation of New Package-Type Substations:

- Substation 1 - 23rd Street, Table H-1
- Substation 2 - 59th Street, Table H-1
- Substation 3 - 103rd Street, Table H-1
- Substation 4 - 147th Street, Table H-2

Conversion of Existing Tie Stations to Substations:

- Substation 5 - 51st Street, Table H-3
- Substation 6 - Riverdale, Table H-3
- Substation 7 - Homewood, Table H-3

Installation of New Package-Type Tie Stations:

- Tie Station 1 - 39th Street, Table H-4
- Tie Station 2 - Wildwood, Table H-5
- Tie Station 3 - 144th Street, Table H-5
- Tie Station 4 - 171th Street, Table H-5
- Tie Station 5 - Olympia Fields, Table H-5

Appendix I - NEW 12.5 kV AC SYSTEM COST BACKUP

The backup for 12.5 kV AC system cost estimate is presented in the following tables:

- Paralleling Station - 1, Table I-1
- Substation - 1, Table I - 2
- Switching Station - 1, Table I-3
- Substation - 2, Table I-4
- Paralleling Station - 2, Table I-5
- Autotransformer Feeder Unit Cost, Table I-6
- Autotransformer Feeder System Cost, Table I-7

Appendix J - NEW 25 kV AC SYSTEM COST BACKUP

The backup for 25 kV AC system cost estimate is presented in the following tables:

- Paralleling Station - 1, Table J-1
- Substation - 1, Table J-2
- Switching Station - 1 , Table J-3
- Substation - 2, Table J-4
- Paralleling Station - 2, Table J-5